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PHILOSOPHY.—*Scientist and theologian?*[1] RAYMOND J. SEEGER, National Science Foundation.

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In the Stanza of the Segnatura in the Vatican, there is a Raphael fresco that is commonly known as the "Disputation on the Sacrament." The official guidebook, however, is of the opinion that the picture might have been more appropriately entitled, "The Triumph of the Church." To be sure, the painting shows a sharp division: above, the Church Triumphant gathered about Christ; and below, the Church Militant concerned with the sacrament. What is most significant to me is the division itself; it seems to be a parable portraying a lofty celestial realm of spirit as a separate sphere, distinct from a nether terrestial world of matter. This distinction, indeed, has not been without supporters. One may recall the Franciscan John Duns Scotus, the Subtle Doctor who argued in the 12th century that it is impossible to harmonize theology based on faith with philosophy based on reason. Philipp Frank notes that "Skepticism towards reason has frequently bolstered faith in revelation." Certainly, there is a modern tendency for many theologians to exclude scientists from exploring the heavenly precincts and for some scientists to banish God from the earthly domain. For example, the Danish philosopher Sören Kierkegaard actually demanded that all existential conclusions be unscientific. In the book "Christianity and Existentialists," edited by C. Michaelson, one finds that "to exist is to value personal authenticity more highly than scientific exactitude." "N. Berdaev's concern is the realm of the spirit, of meaning, of existence—that is primary; the realm of matter is secondary, and he leaves it to the scientist." There is apparently a gentleman's agreement (or is it a cold war?) among some academic specialists to regard science and religion as belonging to separate spheres. No wonder that scientists and theologians are rarely found attending the same professional meetings.

It would seem that the intellectual world could be theoretically described by either science or religion—depending upon one's viewpoint. For example, from a particular metaphysical point of view in which one regards all religiously, the domain of science is automatically included in the realm of religion. On the other hand, from a positivistic point of view in which one regards everything scientifically, the area of religion is naturally included in that of science—as an epiphenomenon at least. Even practically the average person is usually concerned with either science or religion—rarely with both. Here is a man of science. He has had genuine scientific experiences; he believes that these experiences are true and that truth is single. He concludes that if there are any apparent conflicts between religion, which he does not know well, and science, which he does know well, he must choose science. There is a man of religion. He has had genuine religious experiences; he, too, believes these experiences are true and that truth is single. He concludes that if there are any apparent discrepancies between religion, which he knows well, and science which he does not know well, he must choose religion. It is conceivable, of course, that there might be a complete overlapping of

[1] University Lecture, Vanderbilt University, April 1957.

these separate spheres of science and of religion so that they would be identical—or at least equivalent.

It is my personal belief, however, that from a practical point of view, there are two spheres which will never be either completely separated or wholly coincident, but will always overlap to some degree. Each one of us becomes acquainted early with a little religion and with a little science. As we become older, we normally grow both in religion and in science; so, if there is an initial overlapping, there will probably always be an overlapping region of science and of religion, a hazy ground for potential conflict. Actually each of us tends to develop either science or religion to a greater degree so that the problem area of contact always appears relatively small to us personally. Hence we may honestly deny any real problem of science and religion as we knew them. (Any problem of science and religion is necessarily of a personal nature, although affected by social factors; it must be solved ultimately upon an individual basis.) Of course, a state of continually changing problems, personal or social, is intellectually and spiritually healthy; it indicates growth in both science and religion. Thus in the eighteenth century, these problems were centered in the mechanical theories of physics; in the nineteenth century, in the evolutionary theories of biology, and in the twentieth century, in the behavioristic theories of psychology and sociology. Through the very conflict of changing ideas—indeed, because of it—scientists and theologians have both advanced in their understanding of life.

Before looking at these individual spheres and their overlapping, let us consider the problem of science and religion as it actually occurs in the educational process. Some years ago I was giving a college course stressing cultural aspects of science. In that connection, I invited a colleague, a professor of history, to tell how science has influenced political institutions in their development. He began, "Students, what is history? "History,' he said, "is the study of man and his environment." A little later I requested another colleague, a professor of philosophy, to discuss certain philosophical aspects of science. He, in turn, queried, "What is philosophy?" "Philosophy is the study of man and his environment," was his own reply. The next year, I began the course by asking, "What is physics?" "Physics," I admitted, "is the study of man and his environment." You see, even I got the idea; after all, there is only one study—man and his environment. One cannot conceive of an environment without a man, and one cannot conceive of a man without an environment. In this broad sense, only social studies exist; they necessarily include all science. On the basis of this definition, of course, the proper study of man is not man alone; science is concerned not just with environment, but with man and his environment. The problem of man and his environment, however, is so complex that we must approach it along different directions. Now we approach this general problem specifically from the viewpoint of the physical sciences, now directly from the view of the biological sciences, now from that of the psychological sciences, now from that of the social sciences.

Along each of these approaches three questions always arise in our minds. Is this particular view true? Is it real? Is it of value? The clarification and realization of this quest in a particular science are the philosophy of that science. To formulate common questions and to seek common answers, generally speaking, is philosophy, although one must admit that modern philosophizing seem to be concerned with techniques for asking proper questions much more than for attempting valid answers.

There are, indeed, three essentially different attitudes that one may take toward getting answers to these philosophical questions. One may claim dogmatically, "We don't know." Such people are agnostics. Sceptics say doubtfully, "We do not know, but. . . ." Still others urge hopefully, "We do not know, but we are finding out more and more." Such is the attitude of all faithful men; of men who believe that the answers are to be found in our material environment, or in man himself, or in very God. The first group of believers may be called materialists; the second group, humanists; the third, men of religion.

Regardless of what you or I may wish, the fact is the civilization has been built by individuals who have had faith of some kind or other; belief in matter, or belief in man, or belief in God. Philosophy, then, including that particular metaphysical interpretation called theology, necessarily forms an educational link between science and religion. In Raphael's "School of Athens," which is on the wall opposite the "Disputation on the Sacrament," one sees the school of Athens with Plato and Aristotle at its center, Plato looking heavenward, Aristotle pointing earthward—a parable of the diverse theological and scientific attitudes of philosophers.

In any case, as a scientist I start with the fact that "I experience something"; I may not always be intensely alert, or even moderately sensitive, but I do experience something, "my shining hour," "my blue heaven," etc. Now over-all aspects of any experience compel a total (mystical) awareness, which finds expression in religion. Certain phases of an experience present more of an intellectual (i.e., selected) challenge which results in science. The same experiences usually have both aspects in varying degrees. No wonder then, that confusion often exists between science and religion. Evidently, it is necessary right at the start to have clear concepts of both science and theology. It would certainly be presumptuous for me to speak for theology. Accordingly I will limit my definition to science and merely indicate those features that it appears to have in common with theology, and those emphases which seem distinctive to it.

What is science? Science is the result of the use of a scientific method. What, however, is a scientific method? It is a method used by a scientist. In a similar fashion, I believe, one can say that theology is the result of the use of a theological method, and that a theological method is a method used by a theologian (it would not be impossible, though not desirable, to speak of theology as a science.) In order that all this phraseology may not appear to be merely a play upon words, may I say that I am trying to emphasize in both instances the "what" as being less important than the "how," and the "how" as being less valuable than the "who." It is the scientist and the theologian themselves who are most significant. Therefore, we can never regard science solely for the sake of science, or theology primarily for the sake of theology, but rather both science and theology essentially for the sake of man.

In the case of science, we begin with the empirical soil of our personal experiences. First of all, we note that we ourselves are always directly involved. It is I, the subject, who experiences something, the object. The experience always involves a subject and an object; these can never be completely separated from each other. The very attempt to eliminate either the object (extreme existentialism) or the subject (extreme positivism) is itself a subjective process. Dependent upon the field, to be sure various degrees of separation are practicable; greater separation is generally possible in science than in theology; the several sciences themselves differ in this regard. At any rate, there is no such thing as a subject in a vacuum, even though an existentialist might like to denote everyone with a capital "I" or a positivist prefer to label everything with a Roman numeral "I." For anyone to claim, "The subject alone exists, is truly real, not the object, which is dependent, phenomenal," merely begs the question.

After noting this personal involvement, we consider next our sense impressions. First of all, we realize that all our views are based upon an underlying assumption as to the uniformity of nature, not only those views of scientists but also those of theologians, for whom dependability is a sina qua non.

We all start with sense impressions, appearances, or phenomena. These may be more or less vivid; they may be past or present; they may be given or sought—they are the facts of life. There are generally individual variations—no two stars, no two flowers are completely the same. The differences that make for individuality, I believe, are emphasized by theology, whereas the generic similarities are stressed by science. It is undoubtedly true, moreover, that science has consequently searched more for standards of communication, which

have resulted in observed facts that are commonly accepted. It is not that the scientist categorically announces, "Blue is this," but rather "If this is blue, then that is blue." One notes, on the other hand, the difficulties that certain theological schools have in attempting to communicate what appears to be incommunicable, at times intrinsically so, and at other time artifically. Certain theologians, (cf. the theologian Karl Heim's so-called quasi Copernican revolution "which led to the discovery of the non objective I-Thou space"). Certain theologians moreover, have a tendency to use symbolically common words with multiple meanings for certain specific fringe-meanings. In this connection, science undoubtedly has a great advantage. When necessary, it can and does introduce entirely new words which it sharply defines. As that eminent philologist Humpty Dumpty, once remarked, "When I use a word, it means just what I choose it to mean—neither more nor less". Now and then pedantics seem even to delight in using words with rather restricted technical meanings in order to tantalize lay folk who are accustomed to more general usages of them. For example, originally the word myth denoted specifically a story characteristic of primitive people, often with respect to popular supernatural ideas about social and natural phenomena. Such a story might be truthful in its significance, though not necessarily historically true. Much more commonly, however, a myth connotes a tale devoid of truth, or a nonexistent thing or event.

I am even more concerned about current existential statements like this one: "God does not exist." The phrase "to exist" here is supposed to mean "to be human." On the other hand, we are told that "Being connotes matter, the phenomenon; existence connotes the spirit, the noumen." "The empirical world is not God's creation, the spiritual noumenal realm is," suggests another paradox owing to uncommon word usage. The philosopher Martin Heidegger actually defines time "as the temporariness of human beings," in order to set aside the question of so-called objective time. All these phrases may make some sense in the technical usages of the terms. On the other hand, they will be necessarily somewhat confusing to a layman who will probably be regarding the words as familiar ones.

Almost from the beginning of science some philosophers have claimed that science is nothing more than the sum total of observed facts, plus certain inductive inferences—the original positivism formulated by the philosopher August Comte. Later, however, it was recognized that not all observations may be actually recorded; indeed, there is a selection from all the facts—the basis of the scientific positivism expressed by the philosophical physicist, Ernst Mach. More recently we have begun to realize that there is not even a self-evident relationship between the so-called observed facts and their matrix of sense impressions. On the contrary, the relationship itself must be operationally specified in each instance—what is known nowadays as logical positivism. In summary, we all begin with individual experiences. As scientists, we become generally aware of some sense impressions and specifically note certain observed facts among them, as well as their relations. It is always the scientist who observes, the scientist who selects, the scientist who relates! As theologians, too, we may be said to have certain experiences of the whole, involving both sense impressions and particularly significant events, that result similarly in religious facts. Likewise, it is the theologian himself who is impressed, the theologian who selects, the theologian who relates!

Out of the empirical earth, we move up into the rational atmosphere, where we all make a common basic assumption; namely, the intelligibility of the universe. We seek a common-sense interpretation of Nature by applying reason to the empirical earth.

In science we begin with the simple process of identification. We group together similar observed facts. The astronomer, Johannes Kepler, noted that the paths of the planets are all ellipses. Instead of keeping tabular records of all planetary positions, therefore, one can describe them in terms of particular ellipses. Having

identified similar units, childlike we then proceed to make combinations of them in the form of patterns, which involve simply related factors. In many cases, we can express the relations best by means of creative concepts, such as the concept of center of gravity of a ring. One does not find specific gravity per se in nature, one creates this idea through the mind. The relations themselves may be sought primarily for consistency (logic) or for simplicity (with respect to economic or convenient purposes). In any event, it is the scientist who relates the factors; it is the scientist who creates the concepts! The theologian would appear to play a similar role except that the determination of related factors is much more of a complex problem in his case.

From the empirical soil and the rational atmosphere, we move next into the realm of imaginative vistas. I am using the Italian word vista in the same sense as the Greek word theory, meaning view. In this instance we are trying to "save appearances," to look for some reality beyond or some meaning hidden within phenomena. I would call all such theories factitious inasmuch as they are man-made. What is the motivation for such imaginative vistas? It may be heuristic research, it may be intellectual beauty (beauty being something beyond and not within the reach of direct seeking), it may be just common-sense analogues, depending upon individual curiosity or upon social factors (including birth, upbringing and status of the scientist). The more speculative character of theology is generally recognized because of the very comprehensiveness of its problem.

What is all important is the freedom that is involved in making such theories. Abstraction in science is comparatively free like abstraction in art. The artist, Georges Roualt, was once asked how he had learned to portray a white tree in spring. He said it was because he had looked at snow-clad fields in winter. Such association is an irrational element that is prominent also in science. May I call to mind two celebrated examples.

Perhaps it was not an apple that actually struck Isaac Newton that day when he first conceived the possibility of a law of universal gravitation, but there was a thoughtful impact in the idea that the moon might be an apple and fall, or that an apple might become a satellite and encircle the earth. In either case, the same law of gravitation would attract the moon-apple toward the earth—a universal law. Thus Newton arrived at the concept of a universe, distinct from the duoverse that had been prevalent up to his day. Or, again, here is a chain consisting of alternate rings of copper and of iron. We start an electric current in the copper. Instantaneously the encircling iron ring becomes magnetized; as its condition changes the next copper ring exhibits an electric current, which magnetizes the neighboring iron ring, and so on. A disturbance, both electric and magnetic in character, moves along the chain. Let us now remove the iron rings so that only the copper rings are left in place. We find that a disturbance again moves along the remaining rings. We now remove all copper rings except the first one. Once more we find an electromagnetic disturbance, propagated this time out into space—a radio wave. Certainly such a visualization of a physical process in empty space taxes the imagination of each one of us. Picture then that scientist who first formed such an image—the creative scientist who really imagined it before it was realized.

What, you ask, is the value of a theory? A physical theory is essentially an instrument with a prescription of how to use it. As such, it can be employed first of all for description of what has been observed. In this respect, it is cumulative in its growth—it not only interprets past information, but also embraces additional facts as they become observed. All the observed facts must be included in the total description. A similar process might be true for the theology, which, in turn, would have to embrace new religious facts (including so-called revealed ones) as they became known.

A second value of a scientific theory is its ability to predict new phenomena. Here we are reminded of the famous discovery of the planet Neptune. The planet Uranus had been observed not to follow the path predicted by the Newtonian law of gravita-

tion. Someone later suggested that another planet still farther out was responsible for this discrepancy. A calculation was made and a new planet postulated for a certain region in the sky. In that very place the planet Neptune was discovered! This element of surprise in science is truly surprising: It lends credence to our belief in a factitious theory. And yet, we are less shocked when we recall that observed facts always include less than the original sense impressions, all of which are necessarily less than the basic experience themselves: Our observed facts are never abstracted completely and cleanly from the empirical earth. In this characteristic of predictability, theology seems to be woefully wanting in its comparison with science.

We have now all the elements of any scientific method, what we might generally call the scientific method, which is fulfilled in varying degrees depending on the field of inquiry. We begin by asking Nature certain questions; out of the answers we select factors and relate them through creative concepts, we then seek through imaginative associations, a theory that is factitious. On the basis of this new vista, we ask other questions, we obtain additional observed facts, we note other related factors, we formulate a new factitious theory . . . the cycle is repeated in an ever growing spiral—subject always to checks by Nature and by other scientists. The unity of science is made possible by the uniformity of Nature and the community of scientists. It is the very lack of adequate checks that retards more rapid progress on the part of the theologian. The complexity of his material prevents the isolation and experimental control more readily available in a science like physics—not to mention his perpetual problem of communication.

Let us consider again science and philosophy in the light of this outline of the nature of science. First of all, let us glance back historically. We begin with the Greek age of speculative science, when science and philosophy were so intermingled that one could not differentiate them. Aristotle not only played an important role in that period, but established a guiding principle for ages to come by "insisting that philosophy proceeds to what is more self-evident and intrinsically more intelligible". In his Prime Mover, indeed, we have natural theology appearing as natural philosophy. At the same time, however, we note the remarkable contributions of the Ionians who believed that the world of phenomena is understandable and that it is made up of uniform stuff despite the many varieties of forms.

The second great period is what one might call the medieval age of rational science, dominated by the Dominican Thomas Aquinas, the Angelic Doctor who set up two criteria for truth: first, deductibility from intelligible principles, i.e., the "why," and secondly, a check with observations, i.e., the "what". It has always been recognized that the second criterion does not necessarily give a unique solution. As a matter of fact, the Invincible Doctor William of Ockam, the disciple of Duns Scotis, found it advisable to differentiate philosophical truth and religious truth for this very reason.

The third period is the modern age of experiential science, that challenging combination of facts and ideas which has resulted in presentday technology and science. It is understandable that modern science developed first in astronomy where observations had been continuously made and where theories had been successfully formulated. It became evident in the Renaissance that specific astronomical observations could not be deduced from general philosophical principles. Accordingly, there were introduced ad hoc scientific principles of a theoretical character which did describe the observations, but which simultaneously created a gap between theoretical science and philosophy, a gap which has persisted to this very day. It is in this spirit that Newton made his famous remark, "I do not make hypotheses." What he meant was that he did not make hypotheses of a general philosophical nature; of course he did make hypotheses of a strictly theoretical, scientific character.

In this same period we find the beginnings of modern philosophy. We note in this connection the Cartesian dualism of matter and motion as opposed to mind. It was the

philosopher Immanuel Kant, however, who sharply differentiated phenomena, the appearances of things, and things in themselves. He regarded metaphysics as being concerned with ideas that cannot be checked in Nature. Modern opinions still differ widely about the precise relationship between such philosophy and science. In the Encyclopedia Britannica, for example, philosophy is regarded as filling gaps in science; in the Soviet encyclopedia, on the other hand, philosophy is viewed as being essentially different from science. In either case, we continue to see science being excluded from philosophy in the same manner that science is being ignored by theology. Regardless of this intellectual state, modern philosophy and theology both must take account of science. The primary question is how.

A fashionable representative of the metaphysical school today is neo-Thomism. In this case, we have the opinion of the scholastic philosopher Jacques Maritain that science is free in its specific formulations so long as they agree with general philosophical principles. The mathematical physicist Pierre Duhem, however, demanded that philosophy itself choose from among the various possible scientific principles. A more radical emphasis upon the validity of science is the positivistic philosophy derived from August Comte. He introduced sociology, a new discipline which was originally concerned with the social factors pertinent to scientific development. For example, a scientific hypothesis like that of Copernicus may be regarded as desirable because of observational accuracy, because of mathematical advantages, because of common-sense reasonableness, or because of conformity with the predominant philosophy of the times. Whether the geocentric hypothesis or the heliocentric one is preferred depends upon which of these factors are regarded as being of primary importance. At any rate, one concludes with only the relative truth of such a hypothesis. In positivism it is science that provides its own integration and validation. In a certain sense, in the vital issue between metaphysics and positivism, we have revived again the nominalist and realist controversy.

In despair an individual might personally wish to purge science of all philosophy. This prospect, however, appears to be unrealizable both practically and theoretically. Whether or not we desire metaphysical interpretations of science, they will always exist. Philosophy, in general, will always be nearer the common-sense view of average people than science. Science, indeed, usually challenges common-sense opinions. (The common sense of today is the uncommon science of yesterday.) Thus we find in the case of the relativity theory that it was opposed by the Nazis as being too materialistic, but that it was simultaneously opposed by the Soviets as being too idealistic. In the case of the quantum theory, we find George B. Shaw the playwright saying "all is caprice," while the astronomer Arthur S. Eddington claimed it as being a great boon for the idea of a free will and the physicist James H. Jeans was thereby impelled to regard the universe itself as a great thought. In this instance the problem becomes focused on causality, i.e., whether to regard a wave function as fundamental and thereby retain physical causality, or to prefer the square of that function and thereby retain the particle concept. In any event, science is not uniquely determined. Sociological factors are important. The interpretation of science cannot be divorced from science itself—the philosophy of science must be taken into account.

Each one of us, therefore, has apparently three practical choices: (1) to be agnostic and thereby maintain an intellectual vacuum in which moral commitments are meaningless—negativism, (2) or to note indiscriminately all possibilities so that moral commitments are neutralized—positivism, (3) or to proceed wholeheartedly to develop one viewpoint—metaphysics. In reality, I suppose, our actions can never be so simply determined—any course of action may well show traces of all three choices at various times. If any school of thought is momentarily strong, it will emphasize the freedom to develop, and will attempt to force its interpretation upon others. On the other hand, if a group is weak, it will insist upon freedom from philosophical

interpretations, and will try to maintain a purge of philosophical interest.

One more point, what about the truth of a scientific theory? By the term truth here, I am restricting my use to the sense in which we speak of something being "true to observed facts". You recall Plato's cave with the prisoners facing a path having a wall shielding the fire. All they saw were shadows upon the wall, silhouettes. Existentialists argue that the prisoners alone are important—the shadows are too shadowy. Now no one would deny the importance of the prisoners, but the objects producing profile shadows, therefore, do not appear less real. Let us pursue the image a little farther in our own problem.

We begin with the appearances or phenomena on our plane of experience. Out of this plane we select observed facts and construct the world of science. So, too, we can select certain religious facts (including "revealed" ones) and construct a world of theology. One would hardly expect to find a one-to-one correspondence between these two worlds, the world of science and a world of theology, worlds which may be built in quite dissimilar fashions. A continual conflict between theology as a particular philosophy and any philosophy of science would probably be inevitable.

What about the other side of the plane of experience? Is there a world of Nature beyond it?—a world of which this plane is merely an outer surface? If so, is there likely to be a one-to-one correspondence between the superficial world of science and such a fundamental world of Nature? Not necessarily! I do believe, however, that there is a closer over-all approximation of the world of science to the world of Nature as we progress. One gains continually increasing confidence in the descriptiveness and in the predictability of the world of science. As Victor Hugo once said, "La science est l'asymptote de la vérité." To me, the world of science is essentially a symbol pointing to the world of Nature. Likewise, I believe the world of theology can effectively be a symbol pointing to the world of Nature's God.

You may recall that Dante Alighieri despairingly begins his "Divine Comedy," "Midway upon the journey of our life, I found myself in a dark wood, where the right way was lost." He ends it hopefully with "The love that moves the sun and other stars." Early in life Dante had met la donna gentile, the gentle lady (earthly philosophy), interposed between him and la donna gentillisima, the most gentle lady (heavenly theology). But theology was not to be his ultimate satisfaction. In the eyes of his beloved Beatrice (the blessed), transported from earth to heaven, he sees reflected the supernal light. It is the beatific, ineffable vision of God alone that finally fills him with joyful peace at the close of his journey. So, too, I believe, science and theology, including related philosophy, must both point to the same world of Nature and of Nature's God.

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*The knowledge of nature as it is—not as we imagine it to be—constitutes true science.*—PARACELSUS.

PALEONTOLOGY.—*The pelecypod* Euloxa: *Observations on new localities.* DAVID NICOL, *Southern Illinois University, Carbondale, Ill.*

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For my first study on the monotypic genus *Euloxa*, published in 1953, only about a dozen museum specimens were available. Recently I was fortunate enough to find this rare pelecypod in the field and was thus able to observe its stratigraphic occurrence and its paleoecology. I now have 66 measurable specimens and several times that number of fragments or unmeasurable specimens from two new localities. Unfortunately, the *Euloxa* shells from both areas were friable and had to be coated with a solution of alvar and acetone.

A description of the two localities follows, and hereafter in the text they will be referred to only as locality #1 and locality #2.

Locality #1. St. Mary's formation; Hanover County, Va.; 1.5 miles south of Hanover Court House; turn west off U. S. Highway 301 on to State Route 698 to Carry Farm. This locality is a short distance south and west of Cady Station on the Chesapeake & Ohio Railroad. *Euloxa* occurs just below the dam of an artificial lake in a channel cut by the overflow of the dam.

Locality #2. St. Mary's formation; Henrico County, Va.; in a west-facing road cut on U. S. Highway 301; 0.3 mile south of Hanover-Henrico County line. *Euloxa* occurs at the base of the road cut.

These two localities are included in the distribution map of *Euloxa* (Fig. 1).

At locality #1 the thickness of the *Euloxa*-bearing bed is approximately 1 foot. At locality #2 the thickness below the base of the road cut could not be determined. At neither locality could the top or bottom of the St. Mary's formation be seen, and for this reason the position within the formation of the bed containing *Euloxa* could not be ascertained.

On the State Geological Map of Virginia (1928) the areas covered by the two localities are indicated as the Calvert formation; however, the presence of *Euloxa latisulcata*, *Chlamys* (*Lyropecten*) *santamaria*, and *Anadara idonea* proves quite conclusively that these beds belong to the St. Mary's formation. Further paleontologic and stratigraphic work is greatly needed in this area.

## PALEOECOLOGIC OBSERVATIONS

Some paleoecologic inferences can be drawn from the lithology at the two localities. The sediment at both places is exceedingly fine-grained; practically all of it could easily be washed through an 80-mesh screen. It is therefore apparent that the animals lived on a silty or muddy bottom.

Additional paleoecologic inferences can be drawn from a study of the fauna associated with *Euloxa* at the two localities, in some cases by comparing the faunas of the two places (Table 1). Because the shells are friable, it is impossible to identify many of the species, but generic and subgeneric determinations can be made. For most conclusions of a general paleoecologic nature, this amount of systematic allocation is adequate.

Some of the species from both localities appear to be indigenous; other species, by their rare occurrence and poor preservation, appear to have been washed into these areas after death. The latter have been marked with an asterisk in the faunal list and can be omitted from any serious consideration of the ecology at the two localities. This eliminates 10 of the 39 species found at the two places.

At both localities the faunal assemblages are typically marine. A study of the pelecypods (data taken from Keen and Frizzell, 1953, pp. 23–25, and substantiated by Thorson, 1957, pp. 508, 514) indicates that the depth of the water was probably not less than 7 m and not more than 40 m at either locality. A further indication of depth is the presence of the brachiopod genus *Discinisca*, which in modern seas is confined to shallow water.

In terms of number of species, pelecypods predominate at both localities. In number

of specimens, however, gastropods (virtually all *Turritella plebeia*) are almost as numerous at locality #1 as are pelecypods there. The almost total lack of gastropods at locality #2 and the lack of variety of gastropods at locality #1 are probably due to the fact that gastropods do not thrive on a silty substrate. Dr. F. M. Bayer (oral communication) corroborates this statement. His studies of living mollusks reveal that few species of gastropods live on fine mud bottoms, although in such environments the few existing gastropod species may be represented by many individuals.

There is some evidence of carniverous gastropod activity at both localities, but no shells of this type of gastropod were found. At locality #1 one specimen of *Anadara* and four specimens of *Euloxa* had holes in their shells drilled by carniverous gastropods. At locality #2, which had a smaller number of pelecypods, more shells had been attacked by gastropods—one *Mercenaria*, one *Euloxa*, two *Eucrassatella*, and five *Spisula* (*Hemimactra*). Clionid sponge borings in the shells of *Chlamys* are also common at locality #2 but very rare at locality #1.

It is particularly noticeable at locality #1 that the faunal elements are in general represented by small or thin-shelled forms or both. Such genera as *Discinisca*, *Dentalium*, *Turritella*, *Nucula*, *Hiatella*, *Semele*, and *Glossus* all fit this description in one or both respects. At locality #1 this leaves only *Anadara*, which is rare, and *Euloxa*, which is common but is only medium-sized. It has been my observation, as well as that of Dr. Bayer, that large, heavy-shelled mollusks are rarely found on a mucky or silty bottom. At locality #2, where apparently the silty conditions were not so extreme, there are more specimens of large or thick-shelled mollusks: *Euloxa*, which is common, and *Anadara*, *Chione*, and *Eucrassatella*, which are rare. They are greatly outnumbered by small or thin-shelled forms, such as *Dentalium*, *Turritella*, *Chlamys*, *Pododesmus*, *Spisula* (*Hemimactra*), *Corbula*, and *Panope*. The reasons that large, thick-shelled mollusks do not live on a silty substrate are probably mechanical ones.

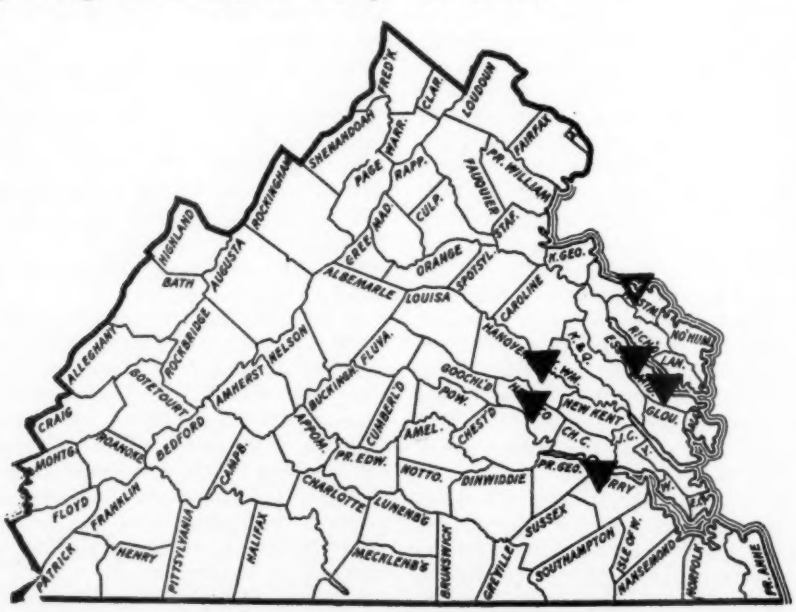


FIG. 1.—Map of part of Virginia showing general localities where *Euloxa* has been reported. Solid triangles, specimens examined by me from these localities. Open triangle, specimens reported from this locality in literature.

TABLE 1.—LIST OF FAUNA FROM THE TWO LOCALITIES

(Asterisk indicates those which were probably washed in after death.)

(Sequence of terms: Abundant, common, rare, very rare.)

| Species | Locality #1 | Locality #2 |
|---|---|---|
| *Anadara idonea* (Conrad) | Rare | Rare |
| *Balanus* sp. | *Very rare | *Very rare |
| *Cerastoderma* sp. | *Very rare | — |
| *Chione* sp. | *Rare | Rare |
| *Chlamys* (*Lyropecten*) *santamaria* Tucker | Common | Common |
| Clionid sp. | Very rare | Common |
| Coral | — | Very rare |
| *Corbula* (*Caryocorbula*) *inaequalis* Say | Common | Rare |
| *Dentalium attenuatum* Say | Common | Rare |
| *Discinisca lugubris* (Conrad) | Common | — |
| *Ecphora* sp. | *Very rare | — |
| *Eucrassatella* sp. | — | Rare |
| *Euloxa latisulcata* (Conrad) | Common | Common |
| *Glossus* sp. | Very rare | — |
| *Hiatella arctica* (Linné) | Very rare | — |
| *Isognomon maxillata* (Deshayes) | *Very rare | — |
| *Mercenaria* sp. | *Rare | *Very rare |
| *Nucula proxima* Say | Abundant | — |
| *Pandora* sp. | Rare | — |
| *Panope* sp. | — | Rare |
| *Parvilucina crenulata* (Conrad) | Rare | — |
| *Pitar* sp. | *Very rare | *Very rare |
| *Pododesmus* (*Monia?*) *philippi* Gardner | Common | Very rare |
| *Semele* sp. | Very rare | — |
| *Spisula* (*Hemimactra*) sp. | Rare | Abundant |
| *Turritella plebeia* Say | Abundant | Rare |

Another observation should be noted. Even in genera like *Chlamys* and *Spisula*, the representatives at both localities tend to run to small size. In the case of *Chlamys* (*Lyropecten*) *santamaria* this is not inherent in the species; specimens collected from a more favorable environment sometimes become twice as large. In the case of *Spisula* (*Hemimactra*) species, there are few relatively large specimens from locality #2 and none from locality #1.

The dominant elements of the fauna at locality #1 are *Turritella plebeia* and *Nucula proxima*; at locality #2, a few miles away and with very similar lithology, *Turritella plebeia* is rare and *Nucula proxima* is absent. The dominant fossil at locality #2 is *Spisula* (*Hemimactra*) species; yet this form is rare at locality #1. Among the less abundantly represented species there are, also, many discrepancies between the two localities. At locality #1 the brachiopod *Discinisca lugubris* is rather common, but not one specimen occurs at locality #2. *Pododesmus* (*Monia?*) *philippi* and *Corbula* (*Caryocorbula*) *inaequalis* are much more common at locality #1 than at locality #2. In addition, *Pandora*, *Parvilucina*, *Hiatella*, *Semele*, and *Glossus*, are represented by few specimens at locality #1, *Parvilucina* being the most common, but are absent at locality #2. The reverse is true of *Panope* and the thick-shelled genus *Eucrassatella*, a few specimens having been found at locality #2 but none at locality #1.

What are the reasons for these faunal differences? That there was little or no dissimilarity in geologic time is indicated by the fact that the genus *Euloxa*, found in the same beds, had only a short life span, probably less than one million years. (See Nicol, 1953a, pp. 706–707.) The differences could be due, at least in part, to the condition of the substrates; i.e., although the matrix is fine-grained at both places, the sediment at locality #2 comprises much more shell material and even the bottom may have been firmer there than at locality #1. The abundance or scarcity of shell material, as well as the matrix itself, is a vital determinant of the type of benthonic animal which will live in an area, and this factor must therefore be taken into consideration when the paleoecology of a locality is studied. Although the depth of the water was probably not more than 40 m at either locality, there may have been enough difference in water depth to contribute to the dissimilarity in the faunal elements of the localities. One other factor may have played a part in the faunal discrepancies. Brachiopods, as exemplified in these two faunas only by *Discinisca lugubris*, are, in general, gregarious animals. This same gregarious habit may occur in some of the

mollusks as well and would explain the presence or absence of a species at a particular locality. There is no evidence that temperature of the water was a factor in the faunal differences between the two localities.

### OBSERVATIONS ON EULOXA

*Euloxa latisulcata* was probably not adapted too well to the conditions on a muddy bottom because all indications so far point to a period of existence for this species of less than one million years. This is a very short life span for a pelecypod species and an extremely short life span for a pelecypod genus. Within the two populations of *Euloxa latisulcata* that I have examined there was a large number of small or immature specimens, many of which were not recovered from the matrix because of their thin and fragile shells. I estimate that 50 per cent of the shells of *Euloxa latisulcata* that I saw were less than 12 mm long, and the largest measurable specimen was 25.8 mm long.

The well-preserved specimens of *Euloxa latisulcata* show distinct seasonal (most likely annual) growth rings on the outside of the shell. The greatest number of growth rings is eight. Most large specimens (20 or more mm in length) have five or six. Specimens of less than 10 mm in length show no growth rings. The latter probably never reached sexual maturity, and perhaps the specimens with only one growth ring also did not.

The nearest living relative to *Euloxa latisulcata* on which I have discovered any data on the matter of reproduction is *Mercenaria mercenaria*. Like many other pelecypods this bivalve is a protandric hermaphrodite—the young specimens nearly always being first male. After the sperm are shed into the water, about half of the population of young individuals becomes female. (See Loosanoff, 1936.) If *Euloxa latisulcata* reproduced in the same manner and if at some time there was a preponderance of sexually immature individuals and males, the survival of the species must have depended on the number of sexually mature females. When the latter group became too small in number, (the growth-ring data indicate that many died before sexual maturity) the species became extinct. This may not be the reason that *Euloxa latisulcata* survived for less than one million years, but, on the other hand, it is a possibility, and it is presented here merely as that. No other reason, backed by any evidence, can be presented at this time.

Some new morphological data, based on examination of a much larger number of specimens, can be added to the observations that I made in my earlier paper. The average specimen is 2 mm longer than high, and even small specimens (less than 12 mm in length) are nearly 2 mm longer than they are high. There is more variation in large specimens (more than 20 mm in length) in the height-length ratio. Some specimens are more than 4 mm longer than high while one specimen has the same height and length measurements. The convexity averages 64 per cent of the length, but this percentage is slightly higher in large specimens. The average height for 68 specimens is 17.0 mm, the length 19.0 mm, and the convexity 12.1 mm. The maximum height observed was 22.4 mm, the length 25.8 mm, and convexity 15.4 mm. Each of these maximum measurements was found on a different specimen. No gerontic individuals were found.

The outline of the valves varies from subquadrate to subcircular. Small specimens generally have a more truncated posterior side. On some specimens, in front of the prominent sulcus on the posterior fifth of the shell, is a faint shallow depression which is wider and more marked toward the ventral border. A similar type of depressed area in about the same area on the outside of the shell, although somewhat larger, is seen in some chionid species.

The anterior pedal retractor muscle scar is small but well marked. It is located under the hinge plate dorsally and slightly posterior to the anterior adductor muscle.

On all large specimens and on most smaller ones, tooth 1 in the right valve is triangular and robust, and it lies perpendicular to the dorsal margin. However, in some of the smaller specimens this tooth is elongate and lies nearly parallel to the

dorsal margin. Apparently the anterior extension of tooth 1 disappears as the individual increases in size.

ACKNOWLEDGMENTS

I am particularly indebted to Shelton P. Applegate, Jr., for the discovery of, and the help in collecting at, the two new localities where *Euloxa latisulcata* was found. Dr. F. M. Bayer was of great assistance in the interpretation of the ecological observations made by the writer.

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## RETARDATION OF COPPER CORROSION BY LIGHT

Sunlight or other intense light, which ordinarily accelerates the corrosion process in metals, has been found to produce an opposite effect on copper oxidation[1]—copper oxide growth is actually retarded by the irradiation. This unusual behavior was observed at the National Bureau of Standards as part of a continuing research project on the corrosion of copper over a wide range of controlled conditions.

In the present investigation, which was partially sponsored by the Corrosion Research Council, Dr. Jerome Kruger of the Bureau's corrosion laboratory immersed copper single crystals in water and found that irradiation retarded subsequent copper oxide growth. Single copper crystals were used because their relatively simple structure gives results that are more easily calculated and understood.

The copper crystals, which were grown from copper of 99.99 percent purity, were submerged in air-saturated, distilled water. A water-jacketed container was used to maintain a constant temperature and to avoid overheating due to intense light. All light was excluded from the highly polished copper crystal except that which shone through a small aperture in the jacket.

After three hours of uniform illumination at room temperature by 3200°K tungsten lamp, the entire crystal sphere was found to be much less oxidized than when illuminated by room light. To study this effect further, one-half of the crystal was illuminated with the intense white light from the tungsten lamp. It was found that the irradiated portion had oxidized at a markedly different rate than the unilluminated area. An electrometric measuring technique showed a film thickness of 120 A on the exposed side and an average film thickness of 500 A on the other side.

When similar light was allowed to impinge on part of a crystal already coated with a thick film (1000–2000 A), the oxide on the illuminated portion became considerably thinner than on the unexposed part of the crystal. X-ray diffraction studies of the films found on both the dark and the irradiated parts of the crystal showed that the films were composed of well-oriented cuprous oxide.

Although the mechanism for this behavior is not known, a possible explanation is a copper-cuprous oxide photocell theory, which centers upon the semiconductance of cuprous oxide. Irradiation would cause an electron flow from the cation-deficient semiconductor film of $Cu_2O$ into the metal. This direction of flow is just opposite to that during oxide growth and hence could block further propagation of the oxide. Other investigators[2, 3] have found that light favors oxidation of aluminum and tantalum whose oxides are cation-excess semiconductors.

The present study indicates that there is a direct correlation between the rate of the oxide formation in water and the underlying crystal structures. Crystallographic orientation studies are now in progress to verify this.

[1] Inquiries concerning further information on copper corrosion should be addressed to Dr. Jerome Kruger, Corrosion Metallurgy Laboratory, National Bureau of Standards, Washington 25, D. C.

[2] N. CABRERA et al., Comp. Rend. Acad. Sci. (Paris) **224:** 1558. 1947.

[3] D. A. VERMILYEA, Journ. Applied Phys. **26:** 489. 1955.

BOTANY.—*Techniques involving the sowing of spores of the Filicinae for artificial culture.* BERNARD T. BRIDGERS, University of Maryland. (Communicated by James H. Hibben.)

(Received January 20, 1958)

Numerous papers have been presented on studies of prothalli of the Filicinae under artificial conditions, and varied techniques have been used for sowing the spores on the substrata. The writer has not found any of these methods to be completely suitable. The object of this paper is to present a technique for sowing the spores which may be found applicable to germination studies as well as studies of growth and development of the prothalli.

Several writers, including Hires (1940) and Steeves, Sussex, and Partanen (1955), have used a bacterial inoculating loop to streak the spores on the surface of nutrient agar. Mohr (1956) described the use of a soft brush, and Reuther (1953) reported that sowing the spores was made through lens paper.

To obtain a consistent homogenous and not-too-compact distribution of spores by these methods is difficult. If the number of spores used is considered significant, these methods are impracticable. A method which has been found more satisfactory than the reported techniques involves the preparation of a spore suspension, using sterile water.

After the spores have been collected they are passed through a fine lens paper to remove any foreign matter, such as portions of sporangia. The spore suspension is then prepared. One is able to estimate the amount of spores to be used in a given volume of water and then the relative number of spores is determined microscopically by observing aliquants of the suspension. However, accuracy is facilitated by using a hemacytometer. This instrument enables one to make a more exact count of the spores to be used.

The suspension is thoroughly agitated in order that the spores will become dispersed throughout the medium. Clumping of spores is as common with ferns as with fungi. To insure a homogenous dispersion of spores Tween 20 may be added aseptically, at a concentration of 5 mg per 100 grams suspension. Then, considering the number of spores desired for the study, a measured amount of the suspension is placed on the medium. A slight rotation of the medium further aids the dispersion of spores.

Practices of disinfestation of spores have been variously discussed. In order to obtain spores free from contaminates, disinfesting the leaf before the opening of the sporangia first was suggested by Perrin (1908) and was later modified by Kleinschmidt (1957). Hurel-Py (1950), however, abandoned the method outlined by Perrin for a direct treatment of the spores. For studies of germination it is considered wise to eliminate such treatments. As has been discussed by Hurel-Py, variation in species must be considered when selecting a concentration of the disinfestant and time of treatment. When the spores are passed through the lens paper most of the foreign matter is removed, and when sowing the spores is performed under aseptic conditions, contamination is held to a minimum. Considering the fact that germination studies may be completed within ten days after sowing, contamination should not be a problem of too much concern.

For longer-termed studies a disinfestant may be used. Steeves et al. (1955) used a 5 percent solution by weight of Pittchlor (manufactured by the Columbia-Southern Chemical Co., Pittsburgh, Pa.). This is a modification of methods described by Hires (1940) and Hurel-Py (1950). No quantitative data are available concerning disinfestation of spores, and the writer feels that this should be done only with caution.

It is common for some germination to occur over a relative long period. To facilitate subsequent growth studies and to obtain a uniform beginning-point of development, the spores may be sown on

sterile water. Uniformly developing prothalli, for example, at the 15- to 25-celled stage, may then be isolated and placed on the medium being investigated. Hurel-Py (1950) has used a similar technique.

Thus, although the technique of suspension of spores presented in this paper is perhaps not applicable to commercial fern producers, it may be helpful in quantitative studies of cellular physiology and morphology in the laboratory.

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# SURFACE ATTACK BY BUFFER SOLUTIONS

Glass, like metal, undergoes a corrosion process when partially immersed in certain solutions. Both glass and metal may also be attacked much more severely at the liquid-air interface than in the bulk volume when immersed in the liquid. Experiments performed at the National Bureau of Standards by R. G. Pike and D. Hubbard have demonstrated that the attack on glass at the surface of a solution at pH 7.0 is equal to the bulk-volume attack in a solution at pH 9.4.[1] This finding is of value in understanding the mechanical weakening of glassy materials at the boundary of an aqueous solution.

An interferometer was used to measure the attack on a glass composed of soda, lime, and silica at the eutectic composition. Specimens were ground and polished to optical flatness and then partially immersed in the attacking solution for a definite period of time at controlled conditions of temperature and pH. After the desired length of exposure they were withdrawn, rinsed and dried, and covered with an optically flat piece of quartz. Using a conventional interferometric viewing apparatus, the displacement of the optical fringes at the liquid-line and in the solution interior was observed. If the specimens were not attacked, the fringes were straight and continuous. However, if the immersed part of the specimen surface had been attacked, each of the vertical fringes was shifted laterally. If the solution had caused swelling of the specimen, the lateral shift was in the opposite direction.

This method also demonstrated the swelling of the glass in the bulk volume of solutions at pH 7 and the etching of the specimen at the surface of the same liquid. The attack in the bulk volume and the attack at the liquid surface were then plotted over a pH range. These curves revealed, for example, that the attack at a solution surface at pH 7 is equal to the attack in the bulk volume of a solution at pH 9.4 (Table 1). This surface attack decreases rapidly at higher pH values, becoming non-detectable at pH 11.8. Unfortunately, because of the chemical durability characteristics of the glass, no differentiation could be made between the attack at the surface and in the interior of solutions more acid than pH 7.

TABLE 1.—DIFFERENCE IN pH VALUES PRODUCING EQUAL ATTACK AT THE SURFACE AND IN THE BULK-VOLUME OF BUFFER SOLUTIONS

| *Bulk-volume alkalinity* pH | *Surface attack equal to that produced by bulk volume alkalinity* pH | *Difference* pH |
|---|---|---|
| 7 | 9.4 | 2.4 |
| 8 | 9.6 | 1.6 |
| 9 | 10.4 | 1.4 |
| 10 | 10.9 | 0.9 |
| 11 | 11.2 | 0.2 |
| 11.8 | 11.8 | 0.0 |

[1] *The increased chemical reactivity of the surface compared with that in the bulk volume of Britton-Robinson universal buffers,* by ROBERT G. PIKE and DONALD HUBBARD, Journ. Res. NBC **59:** 411. December 1957. RP 2811.

# ZOOLOGY.—*Two new crayfishes of the genus* Procambarus *from South Carolina.*

HORTON H. HOBBS, JR., Department of Biology, University of Virginia. (Communicated by Fenner A. Chace, Jr.)

(Received January 31, 1958)

The two crayfishes described herein are members of the Pictus Group, the range of which appears to be restricted to the southeastern part of the United States. Included in this group are: *P. lepidodactylus* Hobbs (1947b: 25), *P. pubescens* (Faxon, 1884: 109), *P. enoplosternum* Hobbs (1947a: 5), *P. litosternum* Hobbs (1947a: 9), *P. pictus* (Hobbs, 1940a: 419), *P. youngi* Hobbs (1942: 131), *P. angustatus* (LeConte, 1856: 401), *P. lunzi* (Hobbs, 1940b: 1), *P. seminolae* Hobbs (1942: 142), *P. lucifugus lucifugus* (Hobbs, 1940a: 398), *P. lucifugus alachua* (Hobbs, 1940a: 402), *P. pallidus* (Hobbs, 940a: 394), and the two species described below.

A discussion of the interrelationships among these crayfishes has been submitted for publication under the title, "The Evolutionary History of the Pictus Group of the Crayfish Genus *Procambarus*" (Hobbs, in press).

**Procambarus hirsutus,**[1] n. sp.

*Procambarus* sp. B. Hobbs (in press).

*Diagnosis.*—Rostrum with marginal spines; upper surface pubescent and hirsute at base of acumen; acumen of moderate length and slender; areola 2.5 to 3.5 times longer than broad, with 8 to 10 punctations in narrowest part, and constituting from 25.5 to 30.0 percent of total length of carapace; postorbital ridges terminating cephalically in sharp spines; a single acute lateral spine on each side of carapace; inner margin of palm of chela of first form male with a poorly defined row of eight to ten small tubercles; male with hooks on ischiopodites of third and fourth pereiopods. First pleopods of first form male asymmetrically situated, reaching coxopodite of third pereiopod, with a rounded hump on cephalic surface, and terminating in four distinct parts: mesial process subspiculiform and directed caudodistad and somewhat laterad; cephalic process similar to mesial process, however, directed more nearly distad; caudal element consists of a prominent rounded protuberance on distal caudolateral portion of appendage—caudal process and adventitious process lacking; central projection corneous, beaklike, and directed caudodistad. Annulus ventralis broader than long with a submedian depression and with an S-shaped sinus that is inclined dextrally. Sternum cephalad of annulus ventralis without prominences.

*Holotypic male, form I.*—Body subovate, compressed laterally, abdomen narrower than thorax (13.7 and 14.5 mm in widest parts respectively). Width of carapace less than depth in region of caudodorsal margin of cervical groove (14.5 and 15.5 mm).

Areola broad (about 2.6 times longer than broad) with 9 or 10 punctations across narrowest part; cephalic section of carapace about 25.7 percent of entire length of carapace.

Margins of rostrum not swollen, subparallel at base but strongly convergent from cephalolateral margin of carapace to about midlength of rostrum where they become subparallel and continue to tips of acute marginal spines. Acumen subspiculiform and extends cephalad to distal end of peduncle of antennule; upper surface of rostrum with a concavity near base and subplane cephalically; entire dorsal surface with setiferous punctations; setae at base of acumen longer and prominent. The usual submarginal row of setiferous punctations present. Subrostral ridges weak but clearly defined, although not evident in dorsal aspect.

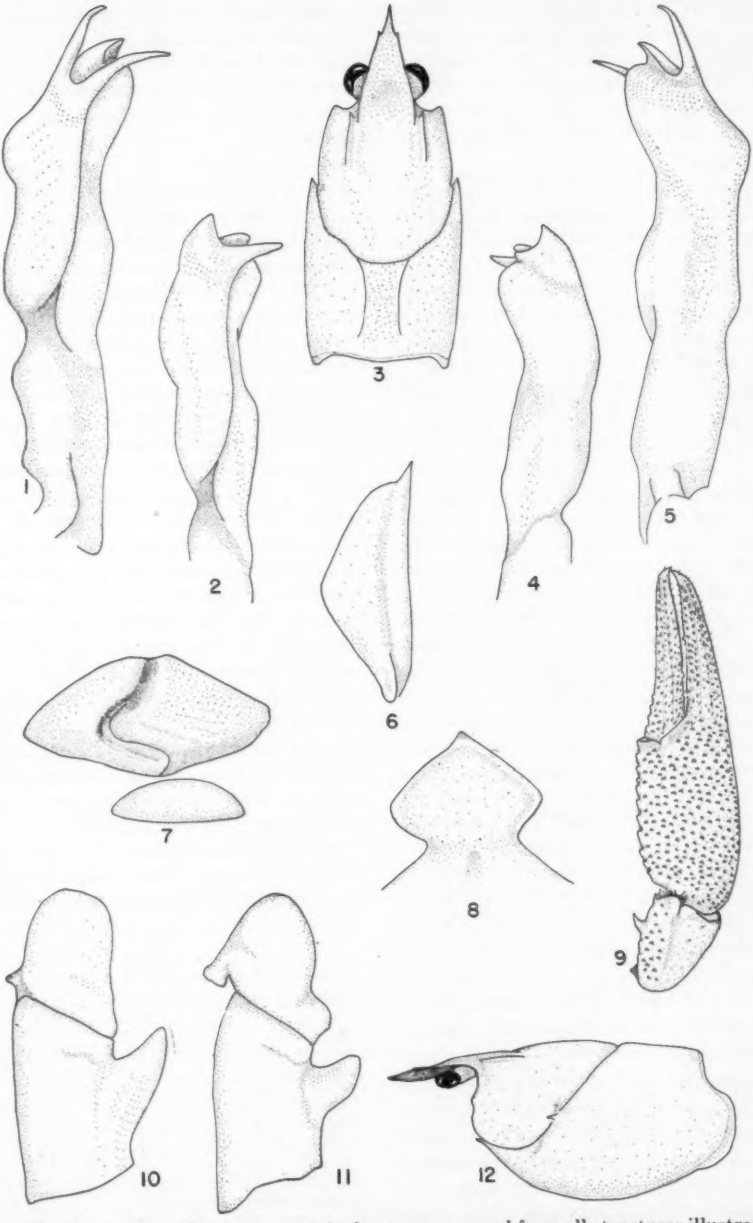
Postorbital ridges prominent, weakly grooved, and terminate cephalically in acute spines; suborbital angle small and forming almost a 90° angle; branchiostegal spine strong and acute. A prominent acute spine present on each side of carapace. Surface of carapace punctate dorsally and strongly granulate laterally.

Abdomen longer than carapace (36.5 and 31.9 mm).

Cephalic section of telson with four spines in each caudolateral corner.

Epistome (Fig. 8) broadly triangular and hirsute.

[1] *Hirsutus*, Latin = shaggy; so named because of the dense pubescence on the rostrum.




FIGS. 1–12.—*Procambarus hirsutus*, n. sp. (pubescence removed from all structures illustrated except in Fig. 9): 1, Mesial view of first pleopod of holotype; 2, mesial view of first pleopod of morphotype; 3, dorsal view of carapace of holotype; 4, lateral view of first pleopod of morphotype; 5, lateral view of first pleopod of holotype; 6, antennal scale of holotype; 7, annulus ventralis of allotype; 8, epistome of holotype; 9, distal podomeres of cheliped of holotype; 10, basipodite and ischiopodite of third pereiopod of holotype; 11, basipodite and ischiopodite of fourth pereiopod of holotype; 12, lateral view of carapace of holotype.

Antennules of the usual form with a strong acute spine on lower surface of basal segment.

Antennae extend caudad to third abdominal segment. Antennal scale (Fig. 6) of moderate width and with a strong spine at extremity of outer distal margin; lamellar portion with no distinct angles.

Right chela elongate, moderately slender, and except for fingers entirely tuberculate. Inner margin of palm with poorly defined rows of tubercles (in silhouette, 10 tubercles may be seen extending above the surface). Lower surface of palm with one tubercle somewhat larger than the others at base of dactyl. Fingers not gaping, both with poorly defined submedian ridges above and below. Upper opposable margin of immovable finger with a row of three small tubercles on proximal third and a larger one below this row near end of middle third. Lateral margin of immovable finger with a row of setiferous punctations, and upper and lower surfaces with similar punctations. Upper opposable margin of dactyl with a row of five small tubercles on proximal two-fifths and two larger tubercles below this row near distal portion of proximal third. Opposable margins of both fingers with crowded minute denticles along entire length. Mesial, upper, and lower proximal portion of dactyl with squamous tubercles; elsewhere with setiferous punctations.

Carpus of first right pereiopod about 1.5 times longer than broad with a broad shallow oblique furrow above; lateral half of podomere with scattered punctations, mesial half tuberculate. Mesial surface with two acute tubercles: one on upper distal margin and a larger one lying at a lower level near midlength. Lower surface with two spinous tubercles on distal margin: one opposite the articular socket on propus and the other mesial to it.

Merus of first right pereiopod with tubercles on upper surface, two of the more distal ones of which are acute and prominent. Lateral surface with scattered punctations; mesial surface with a few squamous tubercles distally. Lower surface with a mesial row of 13 prominent tubercles and a lateral one of 8. Small tubercles irregularly strewn between and to the sides of these two rows. Lower margin of ischiopodite with a row of four prominent tubercles.

Ischiopodites of third and fourth pereiopods bearing hooks (Figs. 10 and 11); hooks simple. Those on third subacute, and those on fourth more truncate, recurved, and opposed by a prominent knob on basipodite.

Coxopodites of fourth and fifth pereiopods with the usual ventrally projecting prominences—those on fourth heavy and rounded; those on fifth compressed.

First pleopod (Figs. 1 and 5) reaching coxopodite of third pereiopod when abdomen is flexed. See diagnosis for description.

*Allotypic female.*—Differs from the holotype in the following respects: Rostrum extends cephalad beyond peduncle of antennule; antennae extend caudad to fourth abdominal segment; cephalic section of telson with only three spines in the caudodextral corner. There is an apparent secondary sexual difference in the chelae in that there is but a single row of minute denticles along the opposable margins of the fingers with a single row of five small tubercles along proximal third of dactyl and only two tubercles on immovable finger. (The holotype, morphotype, and a second form male of approximately the same size as the female have several rows of minute denticles instead of a single one.) Annulus ventralis (Fig. 7) subovate with the greatest length in the transverse axis. A slight elevation sets off an oblique suboval depression through which the S-shaped sinus courses. This elevation, more clearly visible in some specimens than in the allotype, is continuous with a longitudinal furrow cephalically. Sternum cephalic to annulus ventralis broadly excavate with no caudally projecting prominences. (See measurements.)

*Morphotypic male, form II.*—Differs from the holotype in only a few details. Rostrum with margins less convergent; antennae extend caudad

| | Holotype | Allotype | Morphotype |
|---|---|---|---|
| Carapace: | | | |
| Height | 15.5 | 12.9 | 13.9 |
| Width | 14.5 | 11.5 | 13.3 |
| Length | 31.9 | 26.4 | 29.3 |
| Areola: | | | |
| Width | 3.1 | 3.1 | 3.4 |
| Length | 8.3 | 7.0 | 8.2 |
| Rostrum: | | | |
| Width | 5.4 | 4.2 | 4.9 |
| Length | 10.4 | 8.7 | 10.0 |
| Right chela: | | | |
| Length of inner margin of palm | 10.5 | 4.3 | 6.7 |
| Width of palm | 7.7 | 3.3 | 4.7 |
| Length of outer margin of hand | 25.0[2] | 11.2 | 17.0 |
| Length of dactyl | 12.3[2] | 6.2 | 8.9 |

[2] Approximate, tips of fingers broken.

to telson; cephalic section of telson with only three spines in each caudolateral corner; fewer tubercles in each group enumerated above; hooks on third and fourth pereiopods reduced. First pleopod (Figs. 2 and 4) with all terminal elements described for holotype although none is corneous, and each is reduced in size and is more obtuse.

*Measurements* (in millimeters).—As given in table at foot of opposite page.

*Color notes.*—Body dark brown with bright orange mottlings over entire carapace and terga of abdomen. A poorly defined dark saddle-like marking present in the form of a transverse bar across the caudal margin of the carapace and a pair of forward-projecting lateral horns on the lateral surfaces of the branchiostegites. This pattern is frequently modified so that the lateral horns are represented by two lateral pairs of dark spots representing the anterior and posterior portions of the horns. Upper surface of chelae brownish orange with black tubercles, while the tubercles on lower surface are light. Legs dark gray above and below; fingers of chelate appendages greenish blue as are distal podomeres of fourth and fifth pereiopods.

*Type locality.*—Salkehatchie River, 1.9 miles south of Barnwell, Barnwell County, S. C., on State Highway 3. Here the river varies greatly in width, quite narrow in deep areas and more than 50 feet wide in the shallow reaches. The dark brown water flows over a sand and mud bottom and at the bridge are many rocks. *Vallesneria*, *Saururus cernuus*, and *Pontederia* are abundant. My specimens of *P. hirsutus* were collected at night on the open mud bottom and among the eelgrass. Associated with this species here were *P. troglodytes* (LeConte) and *P. echinatus* Hobbs.

*Disposition of types.*—The holotypic male, the allotypic female, and the morphotypic male are deposited in the U. S. National Museum, nos. 101148, 101150, and 101149, respectively. Of the paratypes, one male, form I, one male, form II, and one female are in the Tulane University Collection; two males, form I, two males, form II, and one female are in the collection of the Charleston Museum; 10 males, form I, nine males, form II, 26 females, 17 juvenile males, and 13 juvenile females are in my personal collection at the University of Virginia.

*Relationships.*—*Procambarus hirsutus* has its closest affinities with *P. pubescens* (Faxon) but may be readily distinguished from it by the inflated caudal knob, the absence of the caudal process, and the differences in form of the central projection of the first pleopod of the first form male. The orange mottlings on the carapace of *hirsutus* have also been observed in *P. pubescens*.

*Specimens examined.*—As follows:

**South Carolina:** *Aiken County*—Bridge Creek, 10.6 miles north of Aiken on U. S. Highway 1 (4♂♂I, 3♂♂II, 4♀♀, 8 juv.♂♂, 8 juv.♀♀), April 19, 1955, E. A. Crawford, T. R. Bello, and H. H. H., coll.; *ibid.* (1♀, 2 juv.♂♂, 1 juv.♀), September 13, 1955, H. H. H., coll.; Cedar Creek, 10.6 miles southwest of Wagener on State Highway 215 (1♂II, 8♀♀, 5 juv.♀♀, 3♀♀ with eggs), April 19, 1955, E.A.C., T.R.B., and H.H.H., coll. *Allendale County*—Tributary of Salkehatchie River, 3.4 miles south of Ulmers (2♂♂I) June 7, 1949, R.D. Suttkus, coll.; 7.2 miles east of Allendale on State Highway 641, Miller Swamp Creek (1♂II, 2 juv.♀♀, 1 juv.♀), August 15, 1947, H.H.H., coll.; stream 8.5 miles north of Allendale on State Highway 28 (1♂I, 1♂II, 1 juv.♂, 1 juv.♀), August 15, 1947, H.H.H., coll.; between Appleton and Martin (2♂♂II, 1♀), G. R. Lunz, Jr., coll. *Bamberg County*—Georges Creek, 9 miles south east of Barnwell on State Highway 64 (2♂♂II, 3 juv.♂♂, 2 juv.♀♀), September 3, 1949, W. R. West and H.H.H., coll.; creek, 3.8 miles southeast of Olar on State Highway 64 (1 juv.♂), September 3, 1949, W.R.W. and H.H.H., coll.; Little Salkehatchie River, 4.3 miles east northeast of Ehrhardt on State Secondary Highway 21 (1♂I, 3♂♂II, 7♀♀, 1 juv.♂, 1 juv.♀), June 25, 1956, Anderson, Dunbar, and Smoak, coll.; South Fork of Edisto River, 4.75 miles north of Denmark on U. S. Highway 321 (1♀), August 17, 1955, H. W. Freeman, coll.; Lemon Creek, 8.8 miles south southeast of Bamberg on State Secondary Highway 84 (3♂♂I), June 26, 1956, A., D., and S., coll. *Barnwell County*—Type locality (2♂♂I, 1♂II, 2♀♀), September 3, 1949, W.R.W. and H.H.H., coll.; *ibid.* (7♂♂I, 6♂♂II, 21♀♀, 7 juv.♂♂, 5 juv.♀♀, 1♀ with eggs), April 19, 1955, E.A.C., T.R.B., and H.H.H., coll.; 3.5 miles east of Barnwell on State Highway 70, Bryan's Chapel Creek (3♀♀, 3 juv.♂♂, 3 juv.♀♀), August 16, 1947, H.H.H., coll.; near Robbins (1♀), August 24, 1933, G.R.L., coll.; Hattie Creek, 2 miles northeast of Hattieville (1♀), March 30, 1953, H.W.F., coll.; Creek at west city limits of Barnwell (1♂II, 2♀♀), April 19, 1955, E.C.A., T.R.B., and H.H.H., coll. *Calhoun County*—Spring Creek on U. S. Highway 176 (1♂I), August 11, 1955, H.W.F., coll. *Colleton County*—15 miles northwest of Walterboro on State Highway 64 (2♂♂I), July 11, 1934, E. B. Chamberlain, coll. *Lexington County*—north fork of

Edisto River, 6.2 miles northeast of Wagener on State Highway 215 (1♂II, 2♀♀, 1 juv.♂, 4 juv.♀♀), September 4, 1949, W.R.W., H.H.H., coll.; *ibid.* (2♂♂I, 1♀, 1 juv.♀), April 19, 1955, E.A.C., T.R.B., and H.H.H., coll.; headwaters of Red Bank Creek, 3.2 miles southwest of Red Bank (3♂♂II) July 23, 1953, H.W.F., coll.; Black Creek, 4.5 miles west southwest of Pelion on U. S. Highway 178 (1♂I, 2♀♀), July 5, 1956, H.W.F., coll. *Orangeburg County*—north fork of Edisto River on U. S. Highway 321 (5♂♂II, 5♀♀, 14 juv.♂♂, 12 juv.♀♀), August 15, 1955, H.W.F., coll.; Goodby's Creek on U. S. Highway 176, 2 miles south of junction with U. S. Highway 301 (1♂I, 6♂♂II, 3♀♀, 2 juv.♂♂, 2 juv.♀♀), January 31, 1955, H.W.F., coll.

The range of this species appears to be confined to the drainage systems of the Edisto, Salkehatchie, and Savannah Rivers in South Carolina.

*Remarks.*—*Procambarus hirsutus* appears to be abundant in the Salkehatchie drainage system and is the only member of the Pictus Subgroup represented in it. In the Edisto its range is apparently overlapped by that of an undescribed species of the subgroup, and it shares the Savannah drainage system with *P. pubescens*. Much collecting is needed in the coastal plain tributaries of the Savannah River to determine how widespread these two species are, and to what extent, if any, their ranges overlap.

While there are a number of minor variations in the specimens at hand, chiefly in the shape of the rostrum, none of them is associated with a restricted portion of the range.

As may be noted above, first form males have been collected in January, April, June, July, August, and September. Females with eggs have been found in April.

**Procambarus ancylus,**[3] n. sp.

*Cambarus penicillatus* Hagen (not LeConte), 1870: 54 (in part), figs. 95, 96; Faxon, 1884: 138 (in part); 1885: 36–38 (in part).

Hagen (1870: 54) identified two second form males and two females (M.C.Z. no. 250) as *C. penicillatus*. Faxon (1884: 138) stated that while these specimens may be members of that species "they differ in so many respects, that I suspect they belong to another species." In 1885 (p. 37) Faxon pointed out wherein these specimens differed from the male of *C. penicillatus* (= *P. barbatus*) that he had from Georgia. Faxon (1890: 621) reiterated the same opinion expressed in 1884 concerning these four specimens.

I have examined these four crayfishes and concur with Faxon's opinion that they belong to "another species," and with the additional specimens cited below am convinced that they represent one which has not previously been named.

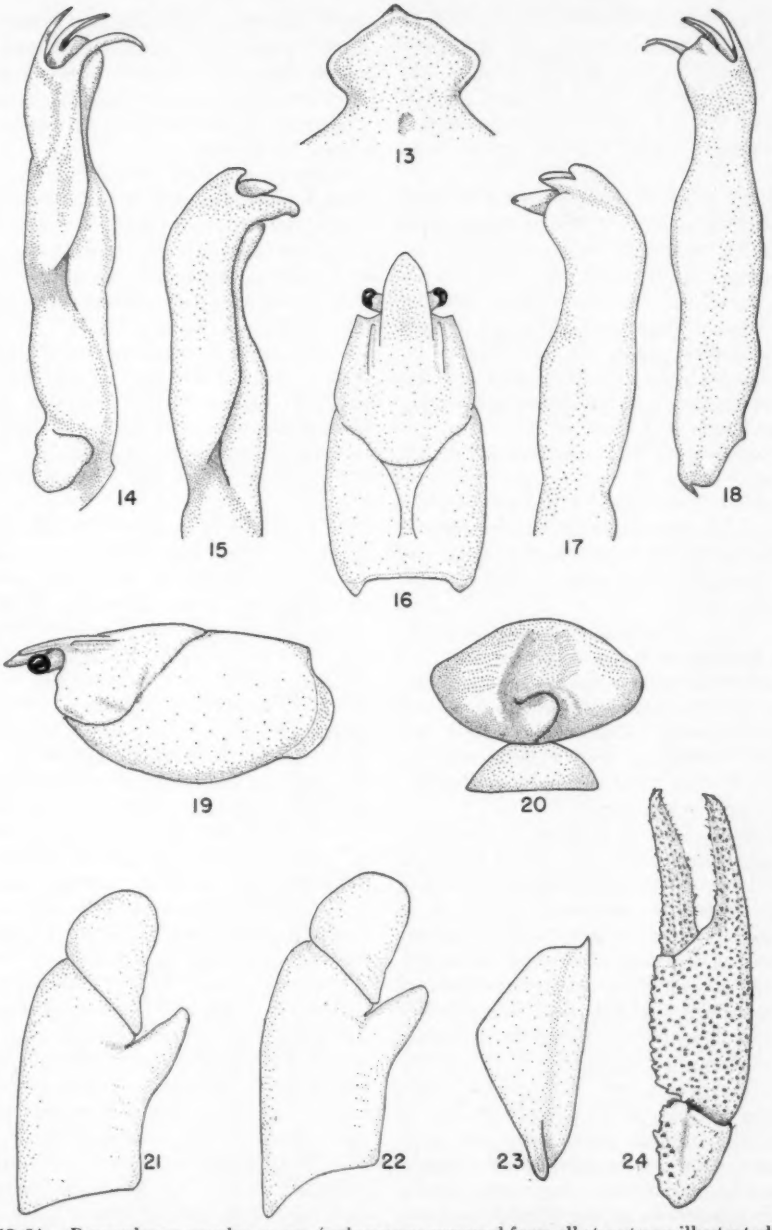
*Diagnosis.*—Rostrum with marginal spines or with uninterrupted margins; acumen variable—short and triangular or subspiculiform; areola 4.8 to 9.0 times longer than broad with two to four punctations in narrowest part; length of areola 32.0 to 35.0 percent of entire length of carapace; inner margin of palm of chela bearing irregularly strewn squamous tubercles; postorbital ridges terminating bluntly or in acute spines; one spine (occasionally two), subacute or tuberculiform, present or absent on each side of carapace. First pleopods of first form male asymmetrically situated, reaching coxopodites of third pereiopods, with a slight hump, sometimes turned mesiad on cephalic surface, and each terminating in four parts: mesial process noncorneous, subspiculiform, and directed caudolaterad with its tip lying lateral to the lateral surface of the main shaft of the appendage; cephalic process noncorneous, long, slender, and directed caudodistad; caudal element represented by the inflated caudal knob; central projection corneous, slender, and directed caudodistad. Annulus ventralis with a marked median longitudinal depression (in ventral aspect) in the caudal half of which courses a reversed C-shaped sinus. Sternum immediately cephalic to annulus ventralis with or without a pair of caudally projecting prominences.

*Holotypic male, form I.*—Body subcylindrical. Abdomen narrower than thorax (11.1 and 13.0 mm in widest parts, respectively). Width and height of carapace subequal in region of caudodorsal margin of cervical groove (13.0 and 12.7 mm).

Areola moderately narrow (8.9 times longer than broad) with one or two punctations across narrowest part; cephalic section of carapace 1.9 times as long as areola (length of areola about 34 percent of entire length of carapace).

Rostrum with margins gently converging to base of acumen where there is only the slightest interruption setting the short acumen off from

[3] *Ancylus*, Greek = curved; so named because of the strongly and similarly curved terminal elements of the pleopod of the male.




FIGS. 13–24.—*Procambarus ancylus*, n. sp. (pubescence removed from all structures illustrated except in Fig. 24): 13, Epistome of holotype; 14, mesial view of first pleopod of holotype; 15, mesial view of first pleopod of morphotype; 16, dorsal view of carapace of holotype; 17, lateral view of first pleopod of morphotype; 18, lateral view of first pleopod of holotype; 19, lateral view of carapace of holotype; 20, annulus ventralis of allotype; 21, basipodite and ischiopodite of third pereiopod of holotype; 22, basipodite and ischiopodite of fourth pereiopod of holotype; 23, antennal scale of holotype; 24, distal podomeres of cheliped of holotype.

remainder of rostrum; acumen reaching base of ultimate segment of peduncle of antennule; margins of rostrum only slightly elevated, not swollen; upper surface slightly concave; a single submarginal row of setiferous punctations extends from base of rostrum to tip of acumen on each side.

Postorbital ridges moderately well developed, only slightly grooved, and terminating cephalically bluntly; suborbital angle almost obsolete; branchiostegal spines small, and not sharply pointed; subrostral ridges moderately well developed but not evident in dorsal aspect. Lateral surface of carapace with only one tubercle on left side slightly larger than others, none on right. Surface of carapace punctate dorsad and weakly granulate laterad.

Abdomen longer than carapace (31.0 and 26.0 mm).

Cephalic section of telson with three spines in the left and four in the right caudolateral corners.

Epistome (Fig. 13) broadly subtriangular and slightly emarginate, and with a small cephalomedian projection.

Antennules of the usual form with a moderate spine on basal segment of peduncle.

Antennae broken but in another specimen from the type locality extends caudad to the third abdominal segment. Antennal scale (Fig. 23) moderately broad and with a small spine at extremity of outer distal margin. Lamellar portion with no distinct angles.

Right chela elongate, palm only slightly inflated and entirely tuberculate. Inner surface of palm with several irregular rows of tubercles, and when viewed in silhouette with 10 or 11 visible. Lower surface of palm with one moderately conspicuous tubercle at base of dactyl. Fingers not gaping. Upper and lower surfaces of both fingers with low submedian ridges flanked on each side by setiferous punctations. Opposable surface of immovable finger with a row of three rounded tubercles on basal half of finger and a single large tubercle below this row at base of distal third. Crowded minute denticles occur along entire opposable surfaces of both fingers. Lateral surface of immovable finger with a row of setiferous punctations. Upper opposable surface of dactyl with a row of five tubercles on basal half. Mesial margin of dactyl with a row of six tubercles on basal half distad of which is a row of setiferous punctations.

Carpus of first right pereiopod about 1.4 times longer than broad with a shallow oblique furrow above. Mesial half of podomere tuberculate and lateral half with scattered punctations. Only four tubercles on podomere conspicuous and these correspond in their positions to the spines described for *P. hirsutus*.

Merus of first right pereiopod with tubercles along upper surface, two of the more distal ones of which larger than others. Lower surface with a lateral row of 11 tubercles and a mesial one of 14; small tubercles scattered between and to the sides of these two rows. Ischiopodite with a row of six tubercles on lower margin.

Ischiopodites of third and fourth pereiopods (Figs. 21 and 22) with hooks; hooks simple, that on fourth slightly heavier than that on third; basipodite of fourth not swollen to oppose corresponding hook on ischiopodite as in *P. hirsutus*. Coxopodites of fourth and fifth pereiopods as in *hirsutus*.

First pleopods (Figs. 14 and 18) asymmetrically situated (the left more caudal in position) and reaching coxopodites of third pereiopods when abdomen is flexed. For description see diagnosis.

*Allotypic female*.—Differs from the holotype in only a few minor details: Epistome narrower but subtriangular; areola 4.8 times longer than wide with three punctations in narrowest part; cephalic section of telson with four spines in each caudolateral corner; chela broader and shorter than in holotype and dactyl with but a single row of five tubercles on basal half; both fingers with a single row of minute denticles. Annulus ventralis (Fig. 20) subovate with the greatest length in the transverse axis; a broad, median, evenly contoured excavation traverses its length; a reversed C-shaped sinus is situated in the caudal half of the declivity. (See measurements.)

*Morphotypic male, form II*.—Differs from the holotype only slightly: Epistome narrower as in allotype; areola 5.8 times as long as wide; cephalic section of telson with three spines in each caudolateral corner; opposable margin of immovable finger of right chela with two tubercles instead of three in basal half; corresponding surface of dactyl with a single curved row of five tubercles. Secondary sexual characteristics with usual reductions. First pleopod (Figs. 15 and 17) with all elements of the holotype clearly represented but cephalic process and central projection shorter and heavier, and the mesial process, while more massive, noncorneous. (See measurements.)

*Measurements* (in millimeters).—As follows:

| | Holotype | Allotype | Morphotype |
|---|---|---|---|
| Carapace: | | | |
| Height | 12.7 | 11.0 | 12.0 |
| Width | 13.0 | 11.0 | 12.0 |
| Length | 26.0 | 22.3 | 24.7 |
| Areola: | | | |
| Width | 1.0 | 1.6 | 1.5 |
| Length | 8.9 | 7.6 | 8.7 |
| Rostrum: | | | |
| Width | 4.1 | 3.6 | 3.8 |
| Length | 6.2 | 5.3 | 6.4 |
| Wight chela: | | | |
| Length of inner margin of palm | 8.5 | 4.6 | 7.5 |
| Width of palm | 7.0 | 4.3 | 6.0 |
| Length of outer margin of hand | 22.2 | 12.1 | 19.0 |
| Length of dactyl | 11.4 | 6.1 | 9.3 |

*Color notes.*—While the colors of the specimens from the type locality are not known the following applies to a first form male collected in Colleton County, S. C. Carapace dark brown dorsally with a median light brown stripe (about the width of the areola) running its full length. In the cephalic region the light stripe is subtended by a pair of dark stripes that extend caudally to the level of attachment of the mandibular muscles where there is a pair of distinct black spots. Lateral portions of branchiostegites with a pair of black stripes (corresponding to the horns of the saddle described for *hirsutus*) below which the color is lighter brown with cream splotches concentrated immediately below the black stripes. Abdomen straw brown above and with the lower portion of each pleoron bearing a light spot. Each epimeron also with a light spot. Uropods and telson concolorous with the abdomen but with dark brown spots. Chelae dark brown above adn with an olive-green cast below.

*Type locality.*—Summerville, Dorchester County, S. C. No description of the habitat from which the crayfish were taken is available.

*Disposition of types.*—The holotype, allotype, and morphotype are in the collection of the Charleston Museum (no. 33: 132). Two paratypic males, form I, one female, and three juvenile females are also in the same collection. One male, form II, and one female are in the collection of the U. S. National Museum. One male, form I, three males, form II, 13 juvenile males, and 47 juvenile females are in my personal collection at the University of Virginia.

*Relationships.*—*Procambarus ancylus*, a member of the Seminolae Subgroup, has its closest affinities with *P. lunzi* from which it may be distinguished readily by the more spiculiform terminal elements of the first pleopod of the male, and by the excavated annulus ventralis of the female. More distantly it is related to *P. seminolae*. All three members of the Seminolae Subgroup frequent lentic habitats (*ancylus* and *seminolae* are also found in lotic situations), and in this respect differ from the typically lotic members of the Pictus Subgroup.

*Specimens examined.*—As follows:

**North Carolina:** *Bladen County*—White Lake (2♂♂II, 2 juv.♀), July 25, 1947, D. G. Frey, coll.; *ibid.* (2 juv.♂♂, 4 juv.♀♀) September 9, 1947, D.G.F., coll.; Singletary Lake (1♀) March 2, 1947, D.G.F., coll.; *ibid.* (1♂I, 1♀), April 11, 1955, J. R. Bailey, coll. *Brunswick County*—Wet Ash Swamp, 8 miles northwest of Shallotte on Route 130 (1♂II, 1♀), March 29, 1949, E. C. Raney, coll. *Columbus County*—White Marsh, 1.9 miles east of Whiteville on U S. Highway 76 (1♂I, 2♂♂II, 2♀♀, 6 juv.♂♂, 7 juv.♀♀), September 1, 1949, W.R.W., H.H.H., coll. **South Carolina:** *Berkeley County*—roadside ditch, 30.8 miles northwest of Charleston on Route 31 (2♀♀) April 20, 1955, T.R.B., H.H.H., coll.; Richmond Plantation, 40 miles up Cooper River from Charleston (2♀♀, 3 juv.♀♀), March 22, 1939, T. K. Ellis, coll. *Charleston County*—U.S.N.M. no. 44438, no locality (1♂II), April 22, 1911, Mearns, Riley, and Brown, coll.; M.C.Z. no. 250, "Charleston" (2♂♂II, 2♀♀); 21.1 miles west of Charleston on U. S. Highway 17 (11 juv.♂♂, 36 juv.♀♀), September 3, 1949, W.R.W., H.H.H., coll. *Colleton County*—pond, 7.1 miles northwest of Walterboro on State Highway 64 (1♂I, 2♂♂II, 3 juv.♀♀), September 3, 1949, W.R.W., H.H.H., coll.; pond, 8.3 miles northwest of Walterboro, State Highway 64 (1 juv.♂, 3 juv.♀♀), August 15, 1947, H.H.H., coll.; roadside ditch, 7.6 miles northwest of Walterboro on State Highway 64 (1 juv.♂, 5 juv.♀♀), August 15, 1947, H.H.H., coll. *Dorchester County*—Summerville (type locality), (3♂♂I, 1♂II, 1♀), May 28, 1932, G.R.L., coll.; drainage ditch in Summerville (1♂II), August 16, 1947, H.H.H., coll. *Kershaw County*—Town Creek, 3 miles southeast of Camden on U. S. Highway 521 (2♂♂I, 3♂♂II, 4♀♀, 1 juv.♂, 1 juv.♀), April 6, 1955, H.W.F., coll. *Lee County*—2.5 miles north of Bishopville on U.S. Highway 15 (1♂I, 1♀, 5 juv.♀♀), December 22, 1956, H.H.H., coll. *Lexington County*—north fork of Edisto River, 6.2 miles northeast of Wagener on State Highway 215 (1 juv.♂, 2 juv.♀♀), September 4, 1949, W.R.W., H.H.H., coll.; Black Creek,

4.5 miles west southwest of Pelion on U. S. Highway 178 (2♂♂ I, 2♀♀), July 5, 1956, H.W.F., coll. *Richland County*—approximately 100 specimens from the eastern part of the county.

*Remarks.*—The variations within the specimens of this species are about as numerous as are to be found in any other species of the genus. The majority of these differences appear to be correlated with the habitat from which the specimens were taken, and there are no variations that have been demonstrated to be clinal or restricted to a certain portion of the range. Specimens collected from burrows or from temporary bodies of water have, in general, a blunt acumen, lack spines on the rostrum, the postorbital ridges, and the sides of the carapace; and most of the spines on other regions of the body are either absent or are reduced to tubercles. In contrast, those specimens collected from permanent bodies of water, whether streams or lentic habitats have acute spines in all the positions mentioned above, and frequently have a spinelike acumen. Of interest is the fact that all small juvenile animals, regardless of the habitat from which they were collected, are similar to adults living in permanent bodies of water. The first pleopod of the male is remarkably uniform throughout the range, and except for the width of the longitudinal excavation of the annulus ventralis it exhibits little variation. The sternum immediately cephalic to the annulus ventralis frequently bears paired caudally projecting prominences.

First form males have been collected in March, April, May, and September, and females with eggs in March and April.

*Acknowledgments.*—I wish to express my appreciation to all those persons who have contributed the many specimens on which this paper is based; their names are cited under the lists of specimens examined. I also wish to thank Miss Margaret Walton, who did the splendid job of inking the figures utilized.

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*Hypotheses, and deductions from these, controlled by sense-observations and analogies with what we know elsewhere, are to be thanked for all of science's results.*—WILLIAM JAMES.

ZOOLOGY.—*On the occurrence of* Streptocephalus similis *Baird in Mexico and the United States.* WALTER G. MOORE, Loyola University, New Orleans, La. (Communicated by Fenner A. Chace. Jr.)

(Received January 2, 1958)

*Streptocephalus similis* is a little-known fairy shrimp which has apparently been taken only twice since its description by Baird in 1852. The type lot was collected by M. Sallé on the island of St. Domingo in the West Indies; Baird's description was based upon specimens in the British Museum. Although incomplete in some respects the description was accompanied by good figures including details of the II antenna of the male.

Packard's (1883) monograph on North American phyllopods quoted the original description verbatim and was unaccompanied by figures. Daday (1910) studied a paratypic series in the collections of the Musée d'Histoire Naturelle, Paris, and presented a detailed description of the animal in his monographic revision of the Anostraca. Daday's treatment was accompanied by an excellent series of original figures including illustrations of anatomical details which had not been recorded by Baird.

A second lot of *S. similis*, collected by H. E. Crampton in Isabella, Puerto Rico, in 1915, is in the collections of the American Museum of Natural History (no. 2914). The material was identified by E. P. Creaser and served as the basis for the latter's treatment of the species in his well-known study (1930) on North American streptocephalids.

An unpublished record, consisting of a single damaged male specimen, is in the collections of the United States National Museum (no. 81601). The specimen was collected by J. W. Price in Jamaica, date unrecorded, and was identified by J. G. Mackin. As far as the writer can determine, no other collections of this species have been reported in the literature. The streptocephalids collected at Elolo in southwestern Ethiopia and recorded as *Streptocephalus similis* Baird by Cannicci (1941) were almost certainly misidentified. These African specimens lacked the definitive features of the II antenna and cercopods which are characteristic of male *S. similis*.

A number of lots of unidentified streptocephalids, taken in northeastern Mexico during the summer of 1954, were presented to the writer by the collector Ernest A. Liner. Many of these specimens proved to be *Streptocephalus similis*. During the summers of 1955, 1956, and 1957, the writer revisited many of Liner's stations and collected at other localities in Mexico and southwest Texas. A number of additional collections of this form were obtained. In view of the almost complete lack of distributional data relating to the species it seemed desirable to place these collections on record.

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## METHODS

Species of the genus *Streptocephalus* are differentiated primarily on the basis of the structure of the second antennae ("claspers"), the frontal

appendages, and the cercopods of adult males. Dissections were made and permanent mounts of these diagnostic structures prepared by a variety of methods including the techniques recommended by Mackin (1942), and by procedures involving the use of water soluble synthetic mountants.

It was found that excellent preparations could be very rapidly produced by dissecting the formalin or alcohol preserved specimens, and transferring the pertinent structures directly to polyvinyl alcohol mountant in concavity slides protected by a cover slip. Of several formulae tested, best results were obtained with that of Gray and Wess (Gray, 1952, pp. 35–36). Preparations so mounted became dry enough to handle within a few hours and little clearing of the structures occurred, a distinct advantage in the present instance since surface features were of primary importance. The customary alcohol and water soluble stains could not be employed with this technique because of the tendency of the stain to "bleed" into the mountant. However useful preparations were made by soaking the preserved specimens, with or without previous washing, in 5% silver nitrate solution and exposing them to direct sunlight for a short time. Specimens so treated were then dissected and the desired structures transferred directly to Gray and Wess's mountant. The deposition of metallic silver on the surface structures provided striking preparations for study as opaque objects by direct illumination. Even more rapid superficial deposition of silver was obtained by adding strong ammonium hydroxide to the silver-nitrate solution in which the specimens were soaked; in this case the necessity of exposing the objects to sunlight was eliminated.

## REVIEW OF DIAGNOSTIC FEATURES

Of the New World streptocephalids only adult males of *S. seali* and *S. similis* are characterized by bowed cercopods, uniformly setose along the margins of the proximal portions and with short curved spines fringing the distal halves. In the case of *S. seali* these cercopods are confluent at their bases and attached to a very short but cylindrical ninth abdominal segment; in *S. similis* the cercopods are separately attached to a small lobiform ninth abdominal segment, triangular in outline. In both species the cercopods of the juvenile and immature males are uniformly setose along the margins from point of attachment to apex; it is only in fully mature specimens that the characteristic hooklike spines appear on the distal portions of these organs.

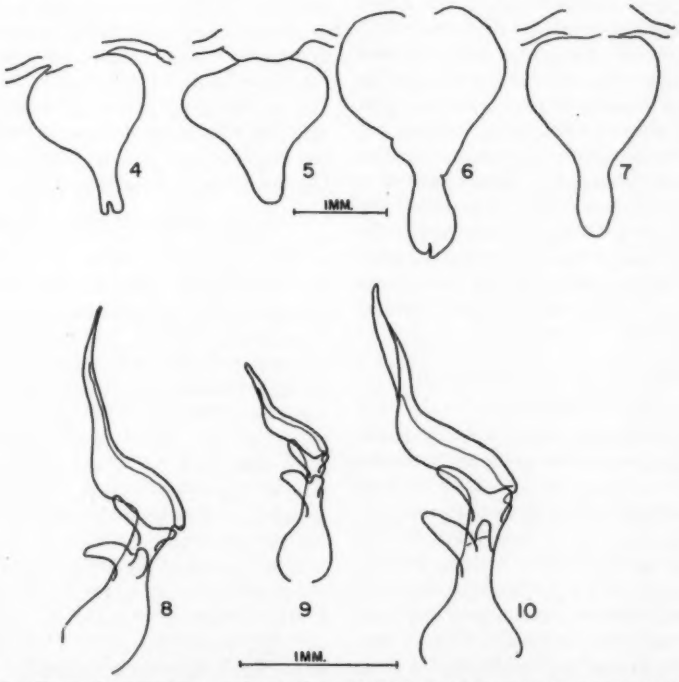
FIG. 1.—*Streptocephalus similis* Baird (Loyola collection no. 994), male, left II antenna, medial aspect. FIG. 2.—*Streptocephalus seali* Ryder (882), right "finger" (inner branch of scissors), anterior surface. FIG. 3.—*S. similis* (994), right "finger," anterior surface.

Of more diagnostic value in the separation of these two species is the character of the second or clasping antennae of the male. This second antenna of the male streptocephalid has usually been described as "3-jointed" or "triarticulate," the segments being identified respectively as a basal joint, a curved intermediate joint, and a characteristic "hand" or "scissors." Linder has shown (1941) that this interpretation is untenable; that streptocephalids have the same two joints to this limb as all Anostraca except the *Polyartemiidae*; and that the supposed second and

third joints are, in reality, simply distal outgrowths from the basal segment. The true second or apical joint is a curved, chitenous process, quite normal in form but pushed to one side by the above-mentioned distal outgrowths.

Diagnostic features of the II antenna of the male of *Streptocephalus similis* are illustrated in Fig. 1. Particular attention is directed to the proximal anterior (or dorsal) margin of the inner, shorter branch of the scissors. In *S. seali* this surface bears two processes or teeth; in *S. similis*, as is apparent from the figure, three such teeth are to be found. Creaser has stated that the middle tooth of the series is less than half the size of the adjacent teeth. Daday has given a somewhat more detailed description of these diversified processes. The anterior tooth, he reported, is large and sharp pointed; the middle, smaller and digitiform; the posterior process is characterized as large and somewhat sickle-shaped, with a bilobed anterior margin.

A comparison of the dorsal surface of the inner, shorter branch of the scissors of *S. seali* and *S. similis* is illustrated in Figs. 2 and 3. These sketches were made with the aid of a camera lucida from polyvinyl alcohol mounted preparations, the appendage in question being oriented by propping it in the desired position against slivers of glass in a concavity slide. *S. seali* (Fig. 2, from a Louisiana specimen) is characterized by the presence of two toothlike processes; the proximal one is broad at the base, sickle-shaped, and turned medially; the distal process is somewhat bilobed, with a short, rounded, laterally directed portion, and a long, slender, pointed tooth, directed medially. The comparable structures of *S. similis*, illustrated by a specimen from Dimmit County, Tex., are shown in Fig. 3. The proximal tooth in this case is likewise broad at the base, sickle-shaped, and turned medially. Lateral and slightly anterior is a much smaller process, directed vertically and confluent at its base with




FIGS. 4–7.—Frontal appendage, male: 4, *S. seali* (882), Louisiana; 5, *S. similis* (A.M.N.H. no. 2914), Puerto Rico; 6, *S. similis* (985), Mexico; 7, *S. similis* (987), Texas.
FIGS. 8–10.—*S. similis*, male, right "finger," anterior surface: 8, (A.M.N.H. no. 2914), Puerto Rico; 9, (982), Mexico; 10 (1017), Mexico.

the proximal tooth. The third or distal process is strongly bilobed with a short, rounded portion directed laterally and a much longer, medially directed, slender tooth.

The frontal appendage of the adult male *Streptocephalus*, variable as it frequently is, nevertheless may be a structure of some taxonomic importance. In distinguishing these two New World streptocephalids with spine-tipped cercopods the character of this appendage seems to afford a criterion of value. Ryder's (1879) original description of *S. seali* notes that the "front of the head is prolonged into a straight beak . . . it is flattened anteroposteriorly, and emarginate at its tip." Creaser refers to a "median lamina extending from forehead, branched into two bulbs at apex." The frontal appendage of a typical Louisiana specimen is illustrated as Fig. 4; the strongly bifurcate tip appears to be quite characteristic of *S. seali*.

In *S. similis*, on the other hand, the tip of the frontal appendage is rounded or only slightly divided. Baird speaks of the "beak . . . flat, rather broad, and slightly lobed at the extremity." Daday refers to a frontal process with a divided apex; his accompanying figure shows this division to be much less pronounced than is the case with typical *S. seali*. Creaser, referring to the specimens collected in Puerto Rico, describes the median lamina as "evenly rounded or slightly bilobed at apex." Fig. 5 illustrates the character of this structure in a Puerto Rican specimen (one of the lot studied by Creaser), while Figs. 6 and 7 show the extremes in variability of the frontal appendage encountered in the specimens collected in Mexico and Texas.

## VARIATION IN THE FEATURES OF THE II ANTENNA

It has been noted that the proximal and middle processes, which are a feature of the dorsal surface of the inner branch of the scissors of male *S. similis*, are confluent at their bases in the Mexican and Texas specimens here considered. Baird's description of the type lot, as well as Daday's more complete treatment of material from the same collection, makes no mention of any such association of these two processes. Creaser, likewise, did not mention any confluence of these processes in specimens from Puerto Rico and the writer's examination of the latter lot verifies the supposition that these teeth, while very closely associated at their bases, nevertheless appear to originate independently from the body of the "finger" (the inner branch of the scissors).

Linder, who examined the damaged Jamaican specimen in the collections of the U. S. National Museum, expressed (personal communication) some doubt as to whether it had been correctly assigned to *S. similis*. He noted that the proximal and middle processes of the finger were "merged in the middle line." This discrepancy presents a not insurmountable difficulty, however, in view of the considerable variation noted in the positions of these two processes in the Mexican and Texas specimens.

Fig. 8 illustrates the quite complete lack of conjunction of these proximal and middle processes in a very typical specimen from the Puerto Rican lot. The third, or distal, process is strongly bilobed, a condition which Linder noted in the Jamaica specimen but which escaped mention (if it occurred) in Baird's and, later, in Daday's description of the Santa Domingo type lot. Fig. 9 shows a maximum degree of coalescence of the proximal and middle processes—a condition uniformly exhibited by a large series of specimens from Tamaulipas, Mexico. Fig. 10 (and also 3, previously cited) illustrates the nearly complete separation of these processes typical of specimens from Nuevo León, Mexico, and Dimmit County, Tex., respectively.

## OTHER MORPHOLOGICAL CHARACTERS

Body size in Anostraca is not a particularly useful taxonomic criterion. The animals become sexually mature (as evidenced by the character of the penes and the II antenna in males, and the occurrence of eggs in the ovisac in females) long before maximum growth is attained. The two recorded collections of *S. similis* indicated a rather small body size for this species; Baird stated the total lengths of males and females to be five-eighths and one-half inch, respectively. Daday noted the size range for the same collection to be 13–15.5 mm for males and 14–16 mm for females. Creaser stated, with reference to the Puerto Rican collection, that "the largest specimen that I have examined is only 17 mm in length."

Total body length, from the front of the head to the tip of the cercopods, was measured in 5 to 10 randomly selected mature individuals of each sex from several of the present collections. Egg counts were also made in the case of the females,

only fully developed, shelled eggs being included in the counts. Typical results are shown in Table 1. The specimens in Lot 982 approximate in size the published collections, while Lots 994 and 1017 consist of notably larger individuals.

TABLE 1.—BODY SIZE AND EGG COUNTS FROM REPRESENTATIVE LOTS OF STREPTOCEPHALUS SIMILIS

| Collection no. | Total body length in mm | | | | Number of eggs in ovisac | |
|---|---|---|---|---|---|---|
| | Males | | Females | | | |
| | Range | Mean | Range | Mean | Range | Mean |
| 982 | 13.0–15.0 | 14.1 | 12.0–12.5 | 12.3 | 51–79 | 66 |
| 994 | 17.5–19.5 | 18.4 | 16.5–17.5 | 17.0 | 135–225 | 180 |
| 1017 | 23.0–26.0 | 24.4 | 23.0–25.0 | 23.7 | 455–541 | 498 |

Egg counts, other than serving as an indication of sexual maturity and relative age, are likewise of dubious taxonomic importance. In *S. seali* it has been shown (Moore, 1955) that egg production commences on a limited scale while the females are still far from maximum size. The process becomes increasingly active later in the life cycle, with the maximum egg production being affected not only by age and body size but also by water temperature, food supply, physiological state of the individual, and perhaps other factors as well. Nevertheless, the larger, older females usually carry considerably more eggs than the smaller individuals—a relationship which is well shown by the data in Table 1.

## LOCALITIES

Fifteen lots of *S. similis* from 11 localities are listed in Table 2. A representative series from each lot has been deposited in the U. S. National Museum. Loyola University collection numbers are indicated in each case; these reference numbers have previously been used in citing the sources of the material used for figures in this paper. The number of males and females in each collection is recorded; in collections numbering several hundred specimens an aliquot of 100 only was sexed. In habitats where one or more additional species of Streptocephalus occurred along with *S. similis* the number of females of the latter species could only be approximated, the distinction being based chiefly on the relative size and shape of the ovisac. However, dependable criteria for the recognition of the females of the various species of streptocephalids have not been established and sex ratios based on such collections of mixed species are merely indicative, at best.

A striking feature of the sex ratios of these collections is the number of instances in which one sex predominated. Even if one eliminates from consideration the smaller lots (those totaling less than 50 individuals), and collections containing streptocephalids other than *S. similis*, this unequal sex ratio prevails in many cases. In the series, limited as above, the three lots with sex ratios approaching unity were noted to be immature or small mature individuals. These three collections, together with their mean lengths, were as follows: no. 983, 11.6 mm; no. 986, 11.8 mm; no. 982, 13.5 mm. The remaining lots, showing unequal sex ratios, were no. 995, 15.5 mm, with a preponderance of females over males of approximately 5 to 1; no. 994, 17.7 mm, with a preponderance of females over males of nearly 6 to 1; and no. 985, 25.2 mm, exhibiting the reverse sex ratio with a preponderance of males over females of 32 to 1.

In his study on *S. seali* the present writer (*op. cit.*) has noted that young populations of this species usually show a uniform sex ratio, with the last survivors of a brood tending to be predominantly of one sex. The data cited above would indicate a similar situation prevails in populations of *S. similis*. Unfortunately successive samplings of particular populations of the latter species throughout the course of their development are not available and the conclusion drawn must, for the present, remain tentative.

Tests were run in the field at each habitat for temperature, hydrogen ion concentration, total alkalinity, turbidity, and, occasionally, for dissolved oxygen and free carbon dioxide. Unmodified water samples were collected for later laboratory determination of chloride, and chloroform-preserved samples were taken for sulphate analysis.

The hydrogen ion concentration of all *S. similis* habitats fell within the range of pH 7.8 to pH 9.0; only two showed a pH of less than 8.2. Total alkalinity was relatively high in all cases; the range was from 54 to 260 p.p.m. with only two pools exhibiting a total alkalinity of less than 100 p.p.m. (one of these tested 97 p.p.m.). Both normal carbonates and bicarbonates contributed to these values. Turbidities were generally high, from 100 to 5000 p.p.m. as deter-

TABLE 2.—NEW LOCALITY RECORDS FOR STREPTOCEPHALUS SIMILIS

| Station No. | Collector | Date | Locality | Number of males | Number of females | Associated Anostraca |
|---|---|---|---|---|---|---|
| 977 | Liner | VII-6-'54 | 26 miles west of Reynosa, Nuevo León, Mexico | 16 | 17 (?) | *Thamnocephalus platyurus; Streptocephalus* sp? |
| 979 | Liner | VII-6-'54 | 0.5 mile southwest of Gen. Bravo, Nuevo León, Mexico | 8 | 9 | None |
| 982 | Liner | VII-13-'54 | 26 miles north of Valles, San Luis Potosí, Mexico | 46 (aliquot of 100 specimens) | 54 | None |
| 983 | Liner | VII-13-'54 | 42 miles north of Valles, Tamaulipas, Mexico | 54 (aliquot of 100 specimens) | 46 | None |
| 985 | Moore & Arata | VII-7-'55 | Near Gen. Bravo, Nuevo León, Mexico (Liner's Sta. 979) | 97 (aliquot of 100 specimens) | 3 | None |
| 986 | Moore & Arata | VII-7-'55 | 0.5 mile west of China, Nuevo León, Mexico | 42 (aliquot of 100 specimens, mostly immature) | 58 | None (?) |
| 994 | Moore & Arata | VII-13-'55 | 6 miles south of Catarina, Dimmit County, Tex. | 12 | 71 | None |
| 995 | Moore & Arata | VII-14-'55 | 4 miles northeast of Rocksprings, Edwards County, Tex. | 17 (aliquot of 100 specimens) | 83 | None |
| 997 | Moore & Arata | VII-15-'55 | 12 miles southwest of Sheffield, Terrell County, Tex. | 18 | 6 (?) | *Streptocephalus* sp? |
| 998 | Moore & Arata | VII-15-'55 | 13 miles east of Sonora, Sutton County, Tex. | 63 | 37 (?) | *Streptocephalus* sp? |
| 1017 | Moore | VI-13-'56 | 44 miles south of Nuevo Laredo, Nuevo León, Mexico | 23 | 8 | *Thamnocephalus platyurus* |
| 1018 | Moore | VI-18-'56 | Same as Sta. 1017 | 10 | 12 (?) | *Streptocephalus* sp? |
| 1019 | Moore | VI-20-'56 | Same as Sta. 997 | 204 | 22 (?) | *Streptocephalus* sp? |
| 1071 | Moore | VI-18-'57 | Same as Sta. 998 | 23 | 48 (?) | *Streptocephalus* sp? |
| 1072 | Moore | VI-18-'57 | 14 miles north of Sonora, Schleicher County, Tex. | 25 | 5 | *Thamnocephalus platyurus* |

mined by the Jackson Turbidimeter, although one productive habitat was characterized by clear water with no measurable turbidity. In these respects *S. similis* habitats did not differ appreciably from ponds in the area which contained only other species of streptocephalids.

Chlorides and sulphates were variable, from a trace to a maximum of 82 p.p.m. $Cl^-$ and 20 p.p.m. $SO_4^=$. The higher values were found in habitats containing only *S. similis*, although one is probably not justified in concluding that this species is therefore more tolerant of these two ions than other streptocephalids since the total number of habitats studied was relatively small.

All previously recorded collections of *S. similis* have come from the West Indies. If one may assume that the species reached continental North America from the islands to the southeast then species-composition data for habitats in the northern and western portions of its present range should be of particular interest. The writer has collected extensively to the western borders of Texas, and north into the Texas-Oklahoma panhandle. The most northwesterly *S. similis* habitat known is a large, semipermanent cattle tank in Terrell County, Tex. This pond was seined by Gordon and Chaney in June 1952; Dr. Gordon provided the writer with a large

collection which included Anostraca and other phyllopods. The habitat was subsequently visited in the summers of 1955 (collection no. 997), 1956 (collection no. 1019), and 1957. The species-composition of the anostracan population, males only, is shown in Table 3.

TABLE 3.—SPECIES-COMPOSITION OF ANOSTRACA POPULATION (MALES ONLY), TERRELL COUNTY HABITAT

| | VI-11-1952 | VII-15-1955 | VI-20-1956 | VI-17-1957 |
|---|---|---|---|---|
| *Streptocephalus* sp. "Type A" | 549 | 154 | 98 | 0 |
| *Streptocephalus* sp. "Type D" | 22 | 2 | 2 | 0 |
| *Streptocephalus similis* | 0 | 18 | 204 | 0 |
| Total | 571 | 174 | 304 | 0 |

In June 1952 the Anostraca population was composed almost entirely of an undescribed streptocephalid, here designated "Type A." A few "Type D" (which may be a variety of *S. texanus*) were included, but no *S. similis* were found in the collection which numbered over 1,200 specimens, females included. Three years later, in July 1955, the same two forms were present but, in addition, 18 male *S. similis* were taken. In 1956 the proportion of *S. similis* had increased to the point where they constituted two-thirds of the male anostracans present. When last visited, in June 1957, it was found that carp minnows had been introduced into the pond and no phyllopods were present. Unless the pond dries completely sometime in the future, killing the fish, it seems unlikely that Anostraca will be taken again from this habitat. Nevertheless, the present rather circumscribed distribution of *S. similis* together with its increase in numbers from zero to a position of predominance within four years in a habitat on the border of its range would indicate that the species may be of rather recent introduction into continental North America, and that it is apparently competing successfully with the native streptocephalids.

## SUMMARY

1. *Streptocephalus similis* Baird, reported only twice since 1852, is here recorded from 11 habitats in Mexico and Texas.

2. The diagnostic characters of the species as illustrated by the present collections are compared with the published descriptions and with certain museum specimens from the West Indies.

3. Sex ratios and egg counts are presented for the recent collections. In general the younger populations of small individuals exhibit a 1:1 sex ratio. Older populations of larger specimens usually showed a striking predominance of one sex over the other.

4. Certain physico-chemical factors of the habitats are summarized. None of the factors measured can be definitely correlated with the occurrence of *S. similis*.

5. The changes in the species-composition of an Anostraca habitat over a period of five years is presented as indicating support for the hypothesis that *S. similis* may be of relatively recent introduction into the North American continent.

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# MARTIAN ATMOSPHERE RESTUDIED

Telescopic observations strongly suggest that Mars has an atmosphere similar to, though more transparent than, the atmosphere of the earth. For more specific information on the Martian atmosphere, astronomers have relied mainly on the spectroscope or spectrograph, instruments that analyze the sunlight reflected from the planet's surface. In principle, the gases present should reveal themselves by their characteristic absorption lines and bands, but results so far have not been conclusive. However, the persistence of inconclusive results despite increasing sensitivity of observing techniques has led to lower estimates of the quantities of gases, such as oxygen, -water vapor, and carbon dioxide, that may be present on Mars.

Another attack on this problem has been made by scientists of the National Bureau of Standards, and they have now completed analysis of the spectrograms obtained during the close approach of Mars in the late summer of 1956.[1] Two husband-and-wife teams—C. C. Kiess, H. K. Kiess, C. H. Corliss, and E. L. R. Corliss—participated in the investigation which was sponsored jointly by the National Geographic Society and the National Bureau of Standards.

Using more sensitive instruments than have been previously applied to this purpose, the scientists photographed the Martian spectrum under the excellent observing conditions at the new high-altitude observatory, operated by the U. S. Weather Bureau, on Mauna Loa volcano in Hawaii. Also, in an effort to extend observations farther into the infrared, another set of spectrograms was made at the Georgetown College Observatory in Washington, D. C.

The investigation concentrated mainly on a search for oxygen and water vapor. The results indicate that both of these, if present, occur in quanties too small to be detected with the equipment used. On the basis of laboratory tests of spectrograph sensitivity to water vapor, this means that there is less $H_2O$ in the Martian atmosphere than there is in a film of water 0.08 mm ($\frac{1}{300}$ in.) thick. The spectrograms also showed no trace of the carbon-dioxide lines that have been observed in Venus, or of spectral lines of the noble gases.

It is believed that these results are not incompatible with the presence of water vapor in amounts sufficient to explain, for example, the transport of water from one polar cap to the other. For it is now fairly well established that the white polar caps of Mars consist of solidified $H_2O$, and it is reasonable to suppose that the seasonal process in which one cap shrinks while the other expands is due to the transfer of water vapor over the Martian surface.

The results do raise the question, however, as to whether the spectroscopic tests hitherto used are delicate enough for the purpose. In the case of $H_2O$ molecules, there is reason to believe that the bands that have been used (because of accessibility to present methods of observing) are not the most sensitive ones. Both theory and experiment indicate that much stronger bands occur farther in the infrared, but different or improved techniques are needed to detect them on Mars. The use of spectrographs mounted in high-altitude balloons, rockets, or artificial satellites will reduce the difficulty further.

## METHODS

The light from Mars, as received near the earth's surface, is really a composite of 3 different spectra. Specifically, it contains absorption lines originating (1) in the reversing layer of the sun's atmosphere, (2) in the atmosphere of Mars, and (3) in the atmosphere of the earth. The wavelengths of the solar lines are accurately known and so can be easily identified. For the much more difficult task of distinguishing lines due to Mars from those due to the earth, 2 methods have been in use.

One method is to observe Mars at "opposition," that is, when Mars, earth, and sun are most nearly in a straight line, with the earth between the other two. Its distance from the earth being a minimum (or nearly so), Mars is then at its brightest. Also, because the distance between Mars and the earth is neither increasing nor decreasing, absorption lines originating in the atmosphere of Mars will not be separated by Doppler shift from those originating in the earth's atmosphere; so that oxygen lines, for example, from Mars will be super-imposed on

[1] For further technical details, see *High-dispersion spectra of Mars*, by C. C. Kiess, C. H. Corliss, Harriet K. Kiess, and Edith L. R. Corliss, Astrophys. Journ. **126**: 579. Nov. 1957.

those from the earth. In such a case, the line may be noticeably intensified or, more likely, distorted; that is, since the Doppler shift is not negligibly small except for a brief interval, the intensity profile of such a line, as measured with a microphotometer, would be asymmetrical. Such distortions might be detected more readily by comparison with corresponding lines in the spectrum of the moon (which has no atmosphere of its own).

The second method is to observe Mars at some time before or after opposition, when the Doppler shift would separate clearly the Martian from the terrestrial lines. Then, if there is oxygen in the atmosphere of Mars, one might expect the oxygen lines caused by the earth's atmosphere to have faint companions separated by the amount of the Doppler shift.

Comparison with the spectrum of the moon, obtained under similar conditions, would allow the Doppler shift to be measured—for example, by the relative displacement of the solar lines. Comparing the Martian spectrum with the more familiar spectrum of the moon would also help in detecting any unknown lines that might show up.

The second method was used in the present investigation. Spectrograms were obtained about 7 weeks before opposition at Mauna Loa and about 6 weeks after opposition at the Georgetown observatory. In the earlier spectrograms the Doppler shift was 0.22 A (angstroms) towards the short wavelengths, and in the later ones 0.25 A towards the longer wavelengths. The measured values of the shift agreed well with the values calculated from the orbital velocities of Mars and the earth.

## INSTRUMENTS

The new study of the Martian spectrum was undertaken in order to see what could be done with the newer aids to observation. These include better diffraction gratings and optical systems, faster photographic plates, and more accurate guiding mechanisms for prolonged photographic exposures.

Before proceeding to Hawaii, the scientists tested the feasibility of using high-dispersion concave gratings for planetary spectroscopy at the Georgetown observatory. Various arrangements were tried out on Jupiter, which was then about as bright as Mars would be in July 1956. The tests justified proceeding with the project and showed that the mounting devised by Wadsworth would be suitable for the grating.

Light is gathered from Mars with a siderostat, a mirror that is motordriven (with manual fine adjustment) so that the light is always reflected in the same horizontal direction towards the rigidly mounted telescope lens and spectrograph. The telescope lens focuses an image of the planet onto a slit, and the light passing through is converted into a parallel beam by a collimating mirror. The beam then strikes and is reflected from a concave diffraction grating which spreads the light out into its components according to wavelength. The light as thus spread out—i.e., the spectrum—falls upon a thin glass photographic plate which is curved to fit the focal plane of the grating.

Two diffraction gratings were selected. One was ruled by R. W. Wood at Johns Hopkins University and has 15,000 lines per in. and a (reciprocal) dispersion of 5 A per mm. The other, ruled by H. G. Gale at the University of Chicago, has 30,000 lines per in. and a dispersion of 2 A per mm. Both have the special virtue of concentrating much of the light in one of the first-order spectra. The telescope lens, 12 in. in diameter and 12 ft. in focal length, was made by J. Clacey, former chief optician at the National Bureau of Standards.

## OBSERVATIONS

The observatory on Mauna Loa offers many advantages to the astronomer. Situated in the midst of the Pacific at an altitude of 11,134 feet, it is free from the ruggedness of terrain that produces turbulence in the surrounding air. Particularly important is its height of about 1 mile above the inversion layer of the atmosphere. This is the level at which the temperature of the air starts to increase with increasing altitude; the bulk of atmospheric dust and moisture are trapped below it.

Built for the joint use of the U. S. Weather Bureau and the National Bureau of Standards, the Mauna Loa observatory was only recently put into service.[2] In fact, the scientists making the present study arrived in time for the dedication ceremonies and began the Mars observations immediately afterwards.

[2] *Mauna Loa observatory for high-altitude research*, NBS Tech. News Bull. **40**: 137. Oct. 1956.

Spectra of Mars and the moon were obtained successively on the same plate, the exposures to Mars lasting 3 hours each. The Wood grating was tried first. The spectrograms proved sufficiently dense to warrant using the more dispersive Gale grating, which was then set up to photograph wavelengths from 5800 to 7400 A.

The Doppler shift is clearly evident in the best spectrograms. In several cases, lines of solar origin that are hidden behind terrestrial lines in spectrograms of direct sunlight are shifted out of their hiding places and appear separately in the spectrum of Mars. If any lines due to water vapor or oxygen in the atmosphere of Mars appeared in the spectrum, they should be shifted by about 0.22 A from those of terrestrial origin. However, there are no companion lines to be seen with the strong lines either in the Fraunhofer *B* band of $O_2$ (roughly 6870 to 6940 A) or in the *a* band of $H_2O$ (roughly 7200 to 7300 A).

Later, the spectrograph was set up again at the Georgetown College Observatory. The aim was to extend observation farther into the infrared than was possible at the time on Mauna Loa. The lower altitude of Washington, D. C. made it necessary to use the Wood grating; exposures to Mars were each about 5 hours long. The portion of the spectrum from 5000 to 9000 A was photographed and scanned for lines of atomic nitrogen, oxygen, and the noble gases, as well as for the *A* band of $O_2$ (about 7600 to 7700 A), the $H_2O$ band at 8200 A, and the $CO_2$ bands at 7820 and 7889 A that were found (1932) by W. S. Adams and T. Dunham, Jr., in the spectrum of Venus. Again the Doppler shift was clearly evident, but none of the lines sought for could be detected.

## INTERPRETATION

The results of this investigation, which extended over a greater wavelength range and utilized higher dispersion than those previously reported, confirm the findings of W. S. Adams and T. Dunham, Jr.,[3] in 1934 and 1941, with respect to the low abundance of oxygen and water vapor in the atmosphere of Mars. The numbers of molecules of both gases are too small to be detected with the equipment used.

[3] *The B band of ozygen in the spectrum of Mars*, by W. S. Adams and T. Dunham, Jr., Astrophys. Journ. **79:** 308. 1934; *Some results with the coudé spectrograph of the Mount Wilson Observatory*, by W. S. Adams and T. Dunham, Jr., Astrophys. Journ. **93:** 16. 1941.

Table 1.—Absorption Bands of $H_2O$ in the Red and Infrared Portions of the Spectrum

The second column gives, for each band, the associated quantum numbers for the 3 fundamental modes of vibration (stretching, bending, and distortion) of the $H_2O$ molecule. The relative transition probabilities are a measure of the intrinsic intensity of the absorption lines.

| Wavelength of band head ($\mu$) | Vibrations $\gamma_1, \gamma_2, \gamma_3$ | Relative transition probability |
|---|---|---|
| 1.379 | (1, 0, 1) | >6 |
| 1.135 | (1, 1, 1) | 1.000 |
| 0.942 | (2, 0, 1) | 0.3 |
| 0.823 | (2, 1, 1) | 0.1 |
| 0.723 | (3, 0, 1) | 0.03 |
| 0.652 | (3, 1, 1) | 0.005 |

In the case of water vapor, tests with a spectrograph of dimensions close to those of the one used in this study were made in the Bureau's spectroscopy laboratory. Under conditions in which the water vapor in the light path was equivalent to a water film 0.15 mm thick, a few of the strongest lines of the *a* band and the one at 8200 A were detectable. Since none of these were detected in the spectrum of Mars, the water-vapor content of its atmosphere must be less than that of a film of water 0.08 mm, or half of 0.15 thick; this is because the light from Mars passes twice through its atmosphere—once coming from the sun and once after reflection from the Martian surface.

The spectrograph used in the present investigation could detect no $H_2O$ bands beyond the one at 0.823 microns (1 micron = 10,000 A). However, theoretical analyses by E. K. Plyler and W. S. Benedict[4] of the Bureau's radiometry laboratory, and others, indicates that the bands at 0.942, 1.135, and 1.379 microns are more intense. As shown in Table 1, the band at 0.942 is about 3 times, the one at 1.135 about 10 times, and the one at 1.379 at least 60 times more sensitive than the band at 0.823. C. C. Kiess was able to detect the bands at 0.942 and 1.135 microns in the laboratory, where a strong source of artificial light was available.[5]

Nonetheless, if water vapor is to be detected

[4] Private communication from E. K. Plyler and W. S. Benedict (1956).

[5] *Wavelengths of rotational lines in the water-vapor bands at 0.93 and 1.13 microns*, by C. C. Kiess, Journ. Res. NBS **48:** 377. 1952. RP2325.

in the relatively weak light from Mars by means of the longer-wavelength bands, more efficient detectors than the present types of photographic plates are needed. Increased sensitivity could also be obtained from balloon-, rocket-, and artificial satellite-based spectrographs. Excellent results have already been obtained in this way on the spectrum of the sun, revealing hitherto undetected portions in the infrared as well as in the ultraviolet.

## AIR-POLLUTION STUDIES

Air zoning, in addition to land zoning, may be essential for American cities of the future. This is the conclusion of Dr. François N. Frenkiel, of the Applied Physics Laboratory of Johns Hopkins University, in a report just published by the Smithsonian Institution.

Air pollution from factory smokestacks, automobile exhausts, smoke from bonfires and chimneys, and various other sources, Dr. Frenkiel points out, each year is causing deaths of a large but undetermined number of persons. Statistics would be very difficult to compile. It is estimated, however, that at least 4,000 died in London during the intense "smog" of the winter of 1952. This smog contained large concentrations of poisonous sulfur dioxide which probably was responsible, directly or indirectly, for most of the fatalities. This particular case was closely associated with peculiar local meteorological conditions and perhaps never will be duplicated.

There can be little question, however, that the air-pollution problem for large cities is becoming more serious year by year. Much can be done to modify conditions. Many large industries in many places have largely eliminated the danger from their smokestacks, but only by quite expensive methods which probably would be beyond the means of individuals.

The only ultimate answer, Dr. Frenkiel believes, is "air zoning" applied both to city extensions and clearance projects. Land zoning now is an established practice to prevent deterioration of residential neighborhoods, the growth of slums, etc.

Zoning air above communities, however, would be a much more difficult problem, involving knowledge of the possible sources of pollution, local geographic and weather conditions, chemical changes of pollutants in the atmosphere, necessity for applying purification methods, and several other factors.

More and more, he points out, the automobile exhaust is looming as a major offender. Most of the concentration takes place at points where there are necessary stops and where many cars pour out their fumes simultaneously. One phase of air zoning may be to rearrange traffic patterns to eliminate as many such points as possible. It would be necessary, in planning for future expansion, to give careful consideration to location and limits of all industrial areas.

"Conventional land zoning," Dr. Frenkiel says, "has for its main purpose promoting art and amenity in urban building. The urban area is divided into residential, commercial, industrial, and other zones with specifications describing the character and the use of the authorized buildings and enterprises.

"Air zoning would specify the allowable levels of concentration [of pollutants] for the atmosphere of each zone. However, building restrictions for each zone must take into account the contributions of the whole urban area to the contamination of its atmosphere. The necessary restrictions will therefore depend on the meteorological conditions of the urban area and result in different requirements for the same classes of zones, according to their location in the area. . . . One must keep in mind that there will always be a certain probability of exceptional meteorological conditions that would produce an abnormally high contamination. The probability of such an occurrence can be reduced to any desirable degree by appropriate zoning regulations." Difficult problems will be involved, he points out, which probably will require the use of high-speed computers.

Using numerous data obtained in some locations, Dr. Frenkiel states, a mathematical model of the sites with their meteorological conditions, traffic pattern, industry, and other pollution sources can be constructed and used to determine the relative responsibilities of each of those sources to the pollution at every location. The author discusses the need for a rational

planning of an urban area taking into account the dangers due to pollution. He says, "There is still need for much research to provide a quantitative determination of the dangers, inconveniences, and costs of atmospheric contamination. Nevertheless, it is a recognized fact that several urban areas produce too much pollution already and that a further increase in the contamination of their atmosphere may become very dangerous under certain meteorological conditions. Urban areas must therefore face the problem of reducing the degree of contamination without at the same time seriously affecting many of those human activities that are responsible for the contamination and which, as much as the clean air, are necessary to the population."

## CRYOSTAT FOR PRECISE TEMPERATURE CONTROL OVER VERY WIDE RANGE

The Cryogenic Engineering Laboratory of the National Bureau of Standards Boulder (Colo.) Laboratories has developed a cryostat that is useful for low-temperature research concerned with the behavior of electronic elements such as a quartz crystal oscillator frequency standard. The work was done in connection with a U. S. Army Signal Corps Engineering Laboratory project.

By employing several convenient liquefied gases successively as refrigerants, the cryostat controls the temperature of an electronic element over a wide range of temperatures—at essentially any value between the boiling point of liquid helium and room temperature. The precision of control ranges from approximately one one-hundredth to one one-thousandth of a degree.

Although numerous cryostats for particular purposes have been described in technical publications, some additional design problems are posed in providing an easily adjustable control system for such a wide temperature range. A method must be provided for obtaining temperatures between those of the available liquefied gases. The system adopted by R. D. Goodwin of the Cryogenic Engineering Laboratory is analogous, in principle, to the operation of an ordinary household electric oven. A thermometer or thermostat in the oven automatically adjusts the electric heat input to balance exactly the heat loss to the cooler environment. The environment employed in the cryostat is at the very low but slightly variable temperature provided by a liquefied gas, such as liquid nitrogen, which is allowed to boil freely at atmospheric pressure. Thermal conduction between "oven" and environment is controlled by adjusting the pressure of a gas employed for heat transfer in the intervening space. The "oven" contains a thermometer and an electric heater. Manual adjustment of the gross level of heating determines how "hot" the cryostat "oven" will be compared to the liquefied gas refrigerant. Automatic control of the heating at this level maintains a constant temperature, despite small changes in the temperature of the liquefied gas environment or heat effects produced in the "oven" by test elements.

The cryostat employs electric resistance thermometers in electric bridge circuits which have been designed both for ease of adjustment over a wide temperature range and for optimum practical sensitivity per unit electric power developed in the thermometer, since the latter is a limitation upon resistance thermometers.[1] The maximum allowable change of temperature of the cryostat "oven" produces a useful signal from the resistance thermometer bridge of the order of one microvolt. Utilization of such a small signal for temperature control requires an electronic amplifier with a gain of about one million. The amplifier must not drift or produce spurious signals (noise) greater than about one-tenth of a microvolt. The amplified signal then is applied to an electronic power regulator for control of the electric heating of the cryostat "oven."[2]

[1] GOODWIN R. D., *Design of simple dc resistance thermometer bridges for wide-range temperature control.* Proc. 1957 Cryogenic Engineering Conf. (Aug. 19, 1957), Boulder, Colo.

[2] GOODWIN, R. D., and PURCELL, J. R., *Direct-coupled power amplifier for cryostat heating control.* Rev. Sci. Instr. **28:** 581. 1957.